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Investigation of Sanitary Landfill Behavior

Volume II
Supplement to the Final Report

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The investigation included studies of leachate migration, the relationship between contaminant concentration and leachate volume, field capacities for various sizes of milled refuse, influence of density and depth on leachate pollutant concentrations, and the relationship of leachate chemical components to each other and to leachate volume.

Volume II contains supplemental studies on stabilization and leachate behavior, including results from an additional year of groundwater monitoring at the field site.

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Volume II. Supplement to the Final Report

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solving, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research, a most vital communications link between the researcher and the user community.

This two-volume report provides long-term information on the release of gaseous and liquid contaminants to the biosphere from decomposing, landfilled, municipal solid waste. Volume I, the comprehensive final report, presents results from a 6-year study. (Preliminary results were published in 1971 - A.A. Fungaroli, Pollution of Subsurface Water by Sanitary Landfills. Report No. SW-12rg, U.S. Environmental Protection Agency, Washington, D.C., 1971.) Volume II contains supplemental studies on stabilization and leachate behavior, including results from an additional year of groundwater monitoring at the field site.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

ABSTRACT

This two-volume study was conducted to predict landfill life through the characterization of gas and leachate generation and pollutant removal. Factors that affect stabilization of the decomposing solid waste were also studied.

The experimental facilities consisted of a sanitary landfill field site for studying gas generation, leachate migration, and groundwater contamination; a laboratory lysimeter for recording leachate quantity and pollutant removal; mini-lysimeters to determine the effect of shredding the refuse; and accelerated column tests for predicting long-term landfill behavior and for identifying the influence of depth and added nutrients on stabilization.

A two-dimensional model of leachate migration patterns was developed. The correlation between the computer solutions to the model and average field concentrations obtained from shallow wells at the field site was good. A zone of contamination in the groundwater was described.

The final report (Volume I) identifies a semi-log linear relationship between contaminant concentrations and leachate volume after field capacity is reached. The supplemental study (Volume II) confirms this relationship.

Field capacities for various sizes of milled refuse are determined along with the influence of density (and depth) on leachate pollutant concentrations. Each chemical component of leachate is positively or negatively correlated with every other chemical component as well as with the volume of leachate.

This report was submitted in fulfillment of Research Grants R800777 and R801947 by Drexel University under the sponsorship of the U.S. Environmental Protection Agency. The two-volume report covers the period September 1967 to October 1974.

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SECTION 1

INTRODUCTION

This report is a supplement to a report on sanitary landfill behavior entitled "Investigation of Sanitary Landfill Behavior, Final Report, Volume I" by A. A. Fungaroli and R. L. Steiner. The final report presents the results of a comprehensive laboratory and field study of sanitary landfill behavior which was conducted over the period from September 1967 to October 1973.

Near the time of termination of the comprehensive study it became recognized that it might be possible to predict sanitary landfill leachate behavior patterns by performing accelerated laboratory tests. One purpose of the study reported herein was to test this hypothesis. A second purpose of the study was to continue to analyze field leachate data to provide a more complete picture of sanitary landfill behavior under field conditions.

The study reported herein had the following broad objectives:

1. Expanded experimental observation of the leachate generated by domestic solid waste, typical of that currently being disposed of in sanitary landfills.

2. Test of the validity of using accelerated leaching tests to predict the longevity of a sanitary landfill's pollutant generation life.

3. Continued experimental observation of the generation and movement of leachate at a field sanitary landfill site.

SECTION 2

SUMMARY AND CONCLUSIONS

This report presents the results of some accelerated leaching column tests performed on solid waste taken from the laboratory lysimeter (Final Report) and a one year continuation of the leachate monitoring program at the field test facility (Final Report).

Column Tests

The column tests consisted of four (4) plexiglas columns which were filled with relatively undisturbed solid waste refuse samples taken from the laboratory lysimeter (Final Report) as it was dismantled.

The four plexiglas columns consisted of sections eight (8) inches (2,032 mm) internal diameter and one (1) foot (3,048 mm) long. As described in this report the one (1) foot (3,048 mm) sections functioned the same as a continuous long seven (7) foot (21,335 mm) leaching column. The advantages of the short columns were easier handling and refuse filling as well as leachate sampling. The column filling and feeding programs are described in the following paragraphs.

The lysimeter cross-section was separated into four (4) quadrants. Starting from the surface, the soil cover was removed first followed by relatively undisturbed one (1) foot (3,048 mm) layers of refuse. Each one (1) foot (3,048 mm) thick refuse layer was trimmed to fit into the plexiglas column. The plexiglas sections were marked in the same order and pattern as removed from the tank to insure proper reassembly orientation.

The four plexiglas test columns labeled A, B, C and D were subject to different water feeding and leachate removal programs. They were:

> Column A: Water addition program was the same as followed in the laboratory lysimeter study (Table 1, Final Report) except that the cycle was suppressed to complete an annual cycle in 5.2 weeks. The quan-

tity of water fed ranged from a low of 23 ml. (equivalent to the month of August) to a high of 652 ml. (equivalent to the month of January). In addition, the amount of leachate removed from the bottom of a section was not fed to the next section. Instead, an equal quantity of distilled water was fed to the next section.

Column B: Water addition program was the same as followed in the laboratory lysimeter study (Table 1, Final Report) except that the cycle was suppressed to complete an annual cycle in 5.2 weeks. The quantity of water fed ranged from a low of 23 ml. (equivalent to the month of August) to a high of 652 m. (equivalent to the month of January). The leachate removed from the bottom of one section was fed to the top of the next section. The amount of leachate removed from a bottom leachate specimen for laboratory analysis was replaced by distilled water before being fed into the next section.

Column C: A uniform water addition (303.5 ml.) equal to the average annual infiltration which was added in a 5.2 week period (Table 1, Final Report) was added on a daily basis. The leachate removed from the bottom of one section was fed to the top of the next section. The amount of leachate removed from a bottom leachate specimen for laboratory analysis was replaced by distilled water before being fed into the next column.

Column D: Water addition program was the same as followed in the laboratory lysimeter study (Table 1, Final Report) except that the cycle was suppressed to complete an annual cycle in 5.2 weeks. The quantity of water fed ranged from a low of 23 ml. (equivalent to the month of August) to a high of 652 ml. (equivalent to the month of January). The leachate removed from a bottom leachate specimen for laboratory analysis was replaced by distilled water before being fed into the next column.

The principal difference between this column and Column "B" was that input water was seeded with a nutrient to test its effect. 24 mg/l of nitrogen was added to the input water. This value was selected on the basis of COD averages for the leachate. The nitrogen was obtained by using 13 amino acids each providing 1 mg N/l with the remainder being supplied by NH_4SO_4. See body of report for complete list of amino acids.

The main purpose of the column tests was to:

1. provide additional experimental observations on the character of the leachate generated by domestic solid waste.

2. test the validity of using accelerated leaching tests to predict the longevity of a sanitary landfill's pollutant generation life.

3. provide experimental information on the effect of nutrient feeding on leachate composition.

From the results of the column tests presented herein, it is concluded that:

1. The transfer of the solid waste from the lysimeter to the columns results in initial higher concentrations in the leachate. This effect results from a loosening and reorientation of the waste during the transfer process. The initially high concentrations in the leachate represent a flushing process during the start of the column tests and is similar to that observed during the initiation of the lysimeter test.

2. The accelerated column tests, while showing marked differences, depending on the feeding program, during the early TIME* periods all gave similar pollutant concentration results at the end of the test.

3. The leachate pH becomes basic as the pollutant concentrations become minimal. In this study final pH values approached 8.

4. The presence of the nutrient tends to retard iron removal and keep leachate concentrations high.

5. While leachate zinc concentrations are generally low, the presence of the nutrient tends to retard the zinc removal rate.

6. Chloride and sodium continue to have similar leachate concentration patterns. The concentration patterns are generally independent of the water feeding program.

7. COD concentrations are somewhat less when using distilled water for each column section (Column "A") as compared to the other columns. However, the presence of nutrients does not have a significant influence on COD reduction rate.

8. The semi-log linear relationship, which was reported in the Final Report, for total pollutant removed versus leachate quantity, above field capacity, is valid until the pollutant is removed. The results clearly demonstrate that the use of the semi-log plot of unit pollutant removed against unit leachate quantity is a valuable tool for predicting contaminant removal behavior patterns.

9. The upper levels of the refuse in the column stabilizes earlier than the deeper levels. This behavior indicates that shallow sanitary landfills will reach stabilization much earlier than deeper ones. That is, a uniform degradation pattern is not obtained in a sanitary landfill. As a result, longer monitoring and control periods are required for deep sanitary landfills.

Field Facility

The additional data collected from the field facility shallow and deep ground water wells provide a more complete picture of subsurface leachate migration patterns.

Of particular interest is the fact that the leachate which discharges from the refuse will concentrate in the upper layer of the ground water system. Further, while pollutant concentration levels do not equal the peak magnitudes reported in the laboratory studies, they do approach the laboratory values. The principal difference being dilution due to ground water mixing. It is noteworthy that most of the pollutant peaks occurred during the period of data collection reported herein. This latter observation suggests that definite trends should be defined prior to termination of any field observations.

The combination of proper field data collection using "shallow" ground water observation wells and the semi-log unit pollutant removed versus unit leachate quantity can provide the basis for a sound procedure for projecting the life expectancy of a sanitary landfill.

SECTION 3

LABORATORY EXPERIMENTAL STUDY

Column Test Arrangement

The laboratory lysimeter (Final Report) was dismantled in May 1972 because leachate pollutant concentrations had reached low but continuously observable levels. However, it was not possible to predict how long the leachate pollutant concentrations would continue to give positive readings. Since it was desirable to determine how long it would take for leachate pollutant concentrations to reach negligible values, plexiglas column tests were established. The plexiglas column leaching tests were developed to provide pollutant concentration patterns under accelerated water feeding programs.

The plexiglas columns (Figure 1) consisted of seven (7) eight (8) inch (2,032 mm) internal diameter tubes one (1) foot (3,048 mm) in length. The bottom of each section had a provision for extracting leachate samples for analysis. The top of each section had a port for feeding in the leachate from the previous section, plus any makeup water to provide constant liquid flow through the refuse. The procedure outlined in the following paragraphs was used in setting up the columns.

The lysimeter cross-section was separated into four (4) quadrants. Starting from the surface, the soil cover was removed first followed by relatively undisturbed one (1) foot (3,048 mm) layers of refuse. Each one (1) foot (3,048 mm) thick refuse layer was trimmed to fit into the plexiglas column. The plexiglas sections were marked in the same order and pattern as removed from the tank to insure proper reassembly orientation.

The four plexiglas test columns labeled A, B, C and D were subject to different water feeding and leachate removal programs. They were:

> Column A: Water addition program was the same as followed in the laboratory lysimeter study (Table 1, Final Report) except that the cycle was suppressed to complete an annual cycle in 5.2 weeks. The quantity of water fed

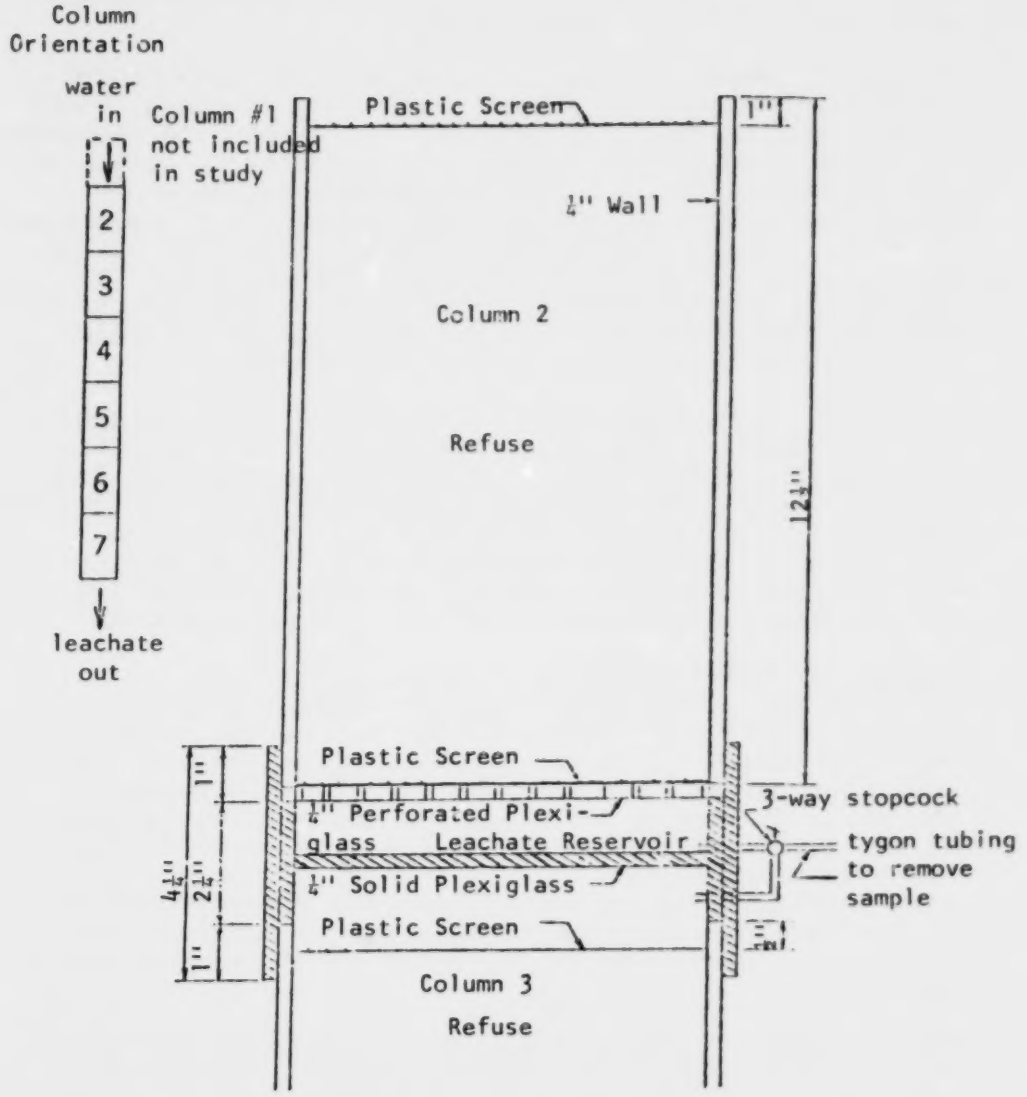


FIGURE 1. SCHEMATIC - PLEXIGLASS COLUMNS

ranged from a low of 23 ml. (equivalent to the month of August) to a high of 652 ml. (equivalent to the month of January). In addition, the amount of leachate removed from the bottom of a section was not fed to the next section. Instead, an equal quantity of distilled water was fed to the next section.

Column B: Water addition program was the same as followed in the laboratory lysimeter study (Table 1, Final Report) except that the cycle was suppressed to complete an annual cycle in 5.2 weeks. The quantity of water fed ranged from a low of 23 ml. (equivalent to the month of August) to a high of 652 ml. (equivalent to the month of January). The leachate removed from the bottom of one section was fed to the top of the next section. The amount of leachate removed from a bottom leachate specimen for laboratory analysis was replaced by distilled water before being fed into the next section.

Column C: A uniform water addition (303.5 ml.) equal to the average annual infiltration which was added in a 5.2 week period (Table 1, Final Report) was added on a daily basis. The leachate removed from the bottom of one section was fed to the top of the next section. The amount of leachate removed from a bottom leachate specimen for laboratory analysis was replaced by distilled water before being fed into the next column.

Column D: Water addition program was the same as followed in the laboratory lysimeter study (Table 1, Final Report) except that the cycle was suppressed to complete an annual cycle of 5.2 weeks. The quantity of water fed ranged from a low of 23 ml. (equivalent to the month of August) to a high of 652 ml. (equivalent to the month of January). The leachate removed from the bottom of one section was fed to the top of the next section. The amount of leachate removed from the bottom leachate specimen for laboratory analysis was replaced by distilled water before being fed into the next column.

The principal difference between this column and Column "B" was that input water was seeded with a nutrient to test its effect. 24 mg/l of nitrogen was added to the input water. This value was selected on the basis of COD averages for the leachate. The nitrogen was obtained by using 13 amino acids each providing 1 mg N/l with the remainder being supplied by $(NH_4)_2SO_4$.

The amino acids were chosen to include the essential amino acid plus others available to give a cross-section of every class of amino acids. The following acids were added:

Tyrosine	25.88 mg/l	(1 mg N/l)
Glutamic acid	21.01 mg/l	"
Cysteine	34.32 mg/l	"
Asparagine	10.72 mg/l	"
Histidine	9.98 mg/l	"
Leucine	18.74 mg/l	"
Alanine	12.74 mg/l	"
Phenylalanine	23.59 mg/l	"
Threonine	17.01 mg/l	"
Methionine	21.31 mg/l	"
Argumine	6.21 mg/l	"

1 mg/l phosphate was added as KH_2PO_4. Thus a 24/1 nitrogen phosphate ratio was achieved.

Solid Waste Composition

The solid waste composition was the same as the final solid waste composition for the laboratory lysimeter. These compositions are presented in Table 1 which is the same as Table 20 in the Final Report.

Leachate Analysis

The leachate was analyzed for pH, iron, zinc, chloride, sodium and COD. These substances were selected from the complete set of analyses performed in the laboratory lysimeter study because all others were of such low concentrations as to not provide any additional useful information. The leachate analysis followed the laboratory procedures used throughout the duration of this study and as described in the Appendix of the Final Report.

Discussion of Results

Figures 2 through 47 show the results of the leachate analysis. All weights, moisture contents, and densities are cited on a dry-weight basis. The following parameters must be defined: TIME* is the time in DAYS* from the start of the plexiglas column tests. Further, DAY* is a day in the scale of the accelerated water infiltration cycle. That is, using DAY* as the time unit for the water feeding cycles as described above for each column, it is possible to generate leachate data for the equivalent of approximately six (6) years of field behavior in approximately eight (8) months. (One year of water infiltration was simulated by a 5.2-week water feeding program.)

TABLE NO. 1

LYSIMETER SOLID WASTE CHEMICAL ANALYSIS
mg/g of refuse - except as noted

	Pre-Test Composition[1]	Post-Test Composition/layer[2] 1st	2nd	3rd	4th	5th	6th
Percent Ether Extractable	1.62	0.423	0.521	2.52	2.20	2.359	2.634
Percent Water Extractable	6.78	1.402	2.506	1.95	2.86	6.128	5.33
Solid Chemical Oxygen Demand	1283	733	768	960	981	1045	1086
Solid Nitrogen	2.97	1.95	2.29	0.0	0.0	0.0	1.42
	Water Soluble Chemical Composition						
Iron	0.602	0.091	0.112	0.101	0.587	0.050	0.036
Zinc	0.595	0.011	0.017	0.005	0.002	0.021	0.023
Nickel	0.034	0.021	0.011	0.022	0.029	0.056	0.029
Copper	0.025	0.007	0.005	0.011	0.007	0.009	0.007
Calcium	0.856	0.338	0.376	0.540	0.668	0.881	0.746
Phosphate	0.293	0.006	0.001	0.008	0.012	0.002	0.001
Chloride	2.003	0.200	0.211	0.259	0.126	0.299	0.578
Sodium	1.950	0.095	0.043	0.099	0.467	0.635	0.683
Ammonia Nitrogen	0.02	0.019	0.0	0.001	0.0	0.0	0.0
Organic Nitrogen	0.35	0.066	0.044	0.075	0.111	0.111	0.157
Chemical Oxygen Demand	25.25	1.25	0.943	3.063	8.46	11.83	10.47

1. Average of all refuse placed in lysimeter.

2. Average of four samples in each layer. Each layer approximately twelve inches thick. First layer taken from top of refuse. Sixth layer taken from bottom.

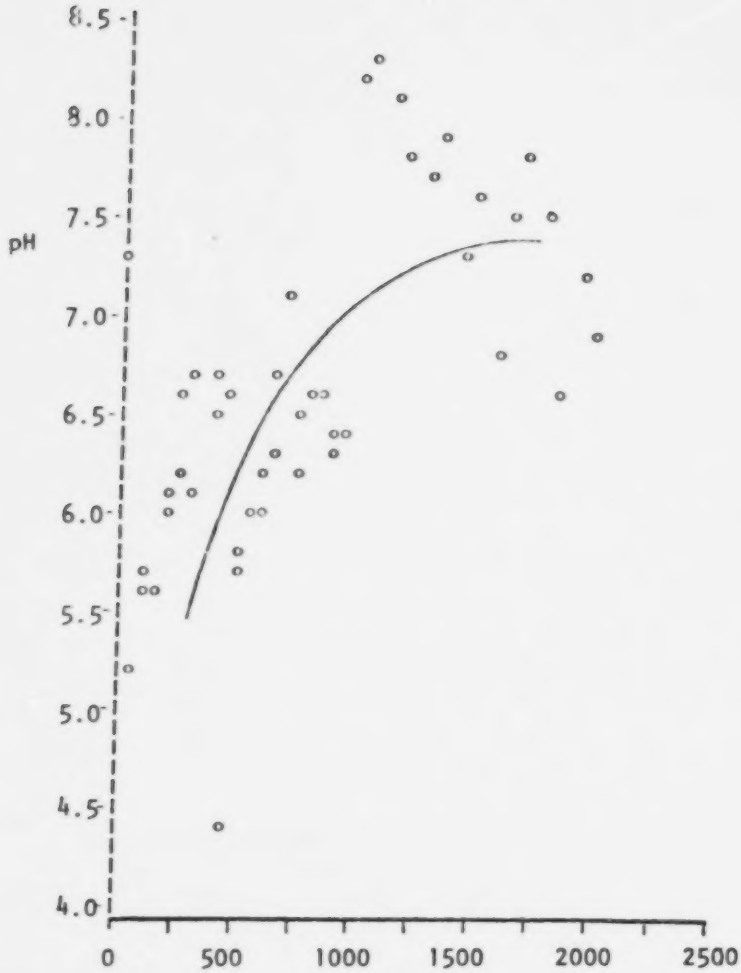


FIGURE 2. COLUMN A - pH
BOTTOM LEACHATE

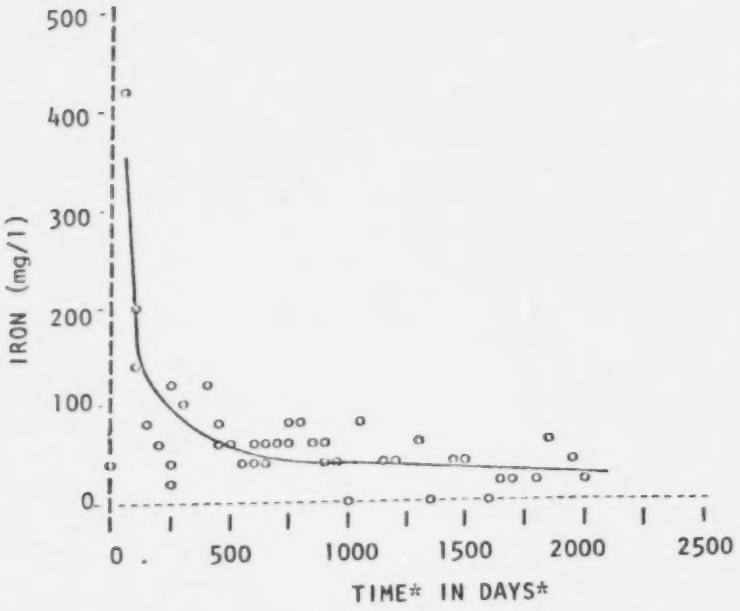


FIGURE 3. COLUMN A - IRON CONCENTRATION
BOTTOM LEACHATE

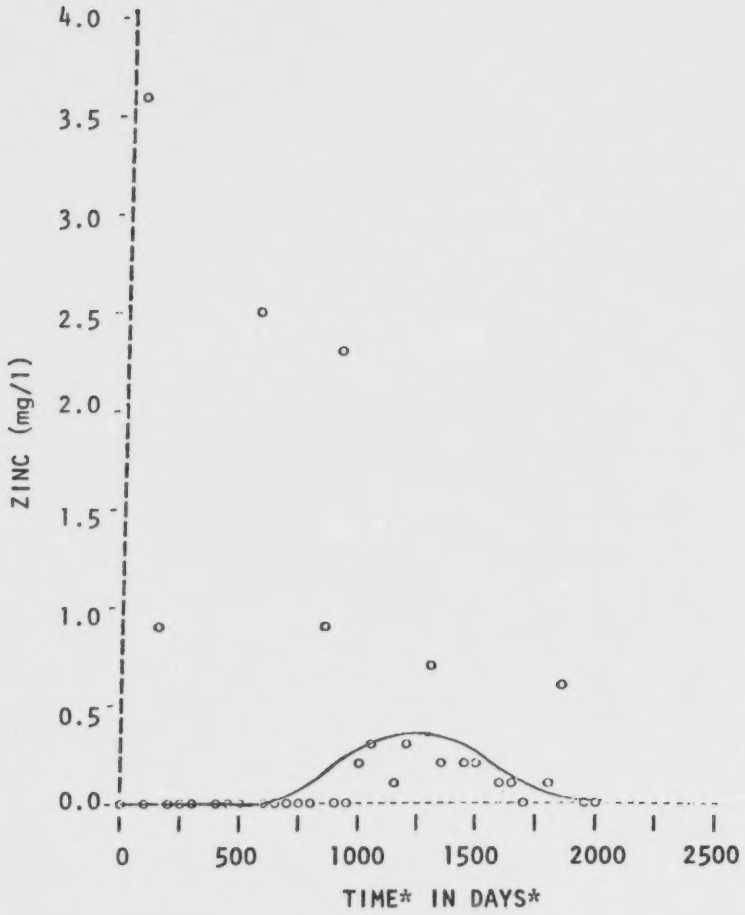


FIGURE 4. COLUMN A - ZINC CONCENTRATION
BOTTOM LEACHATE

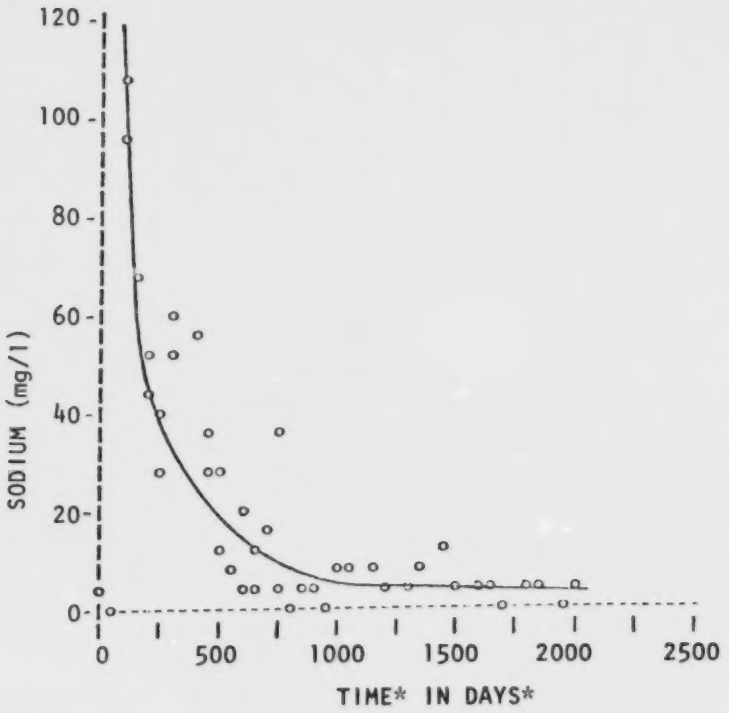


FIGURE 5. COLUMN A - SODIUM CONCENTRATION
BOTTOM LEACHATE

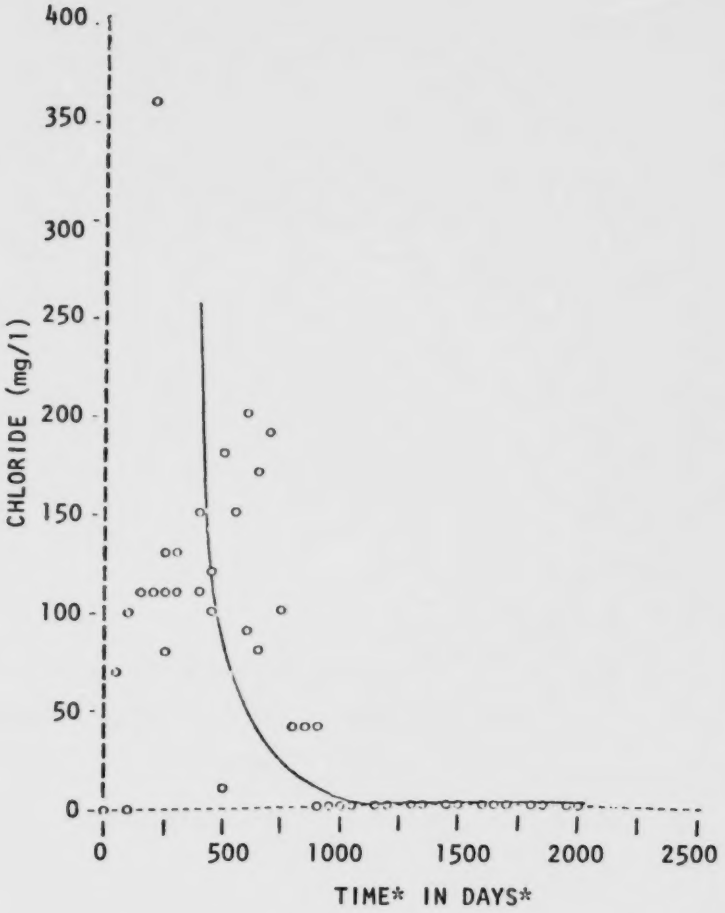


FIGURE 6. COLUMN A - CHLORIDE CONCENTRATION
BOTTOM LEACHATE

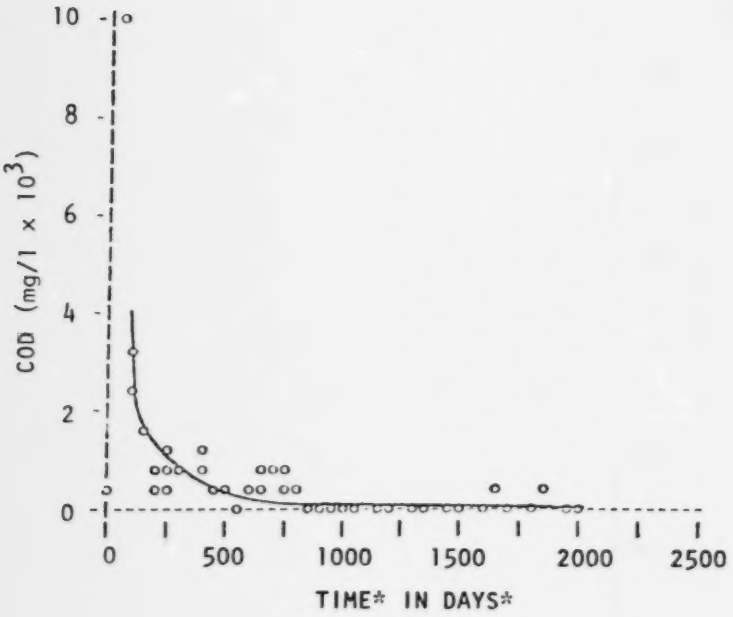


FIGURE 7. COLUMN A - COD CONCENTRATION
BOTTOM LEACHATE

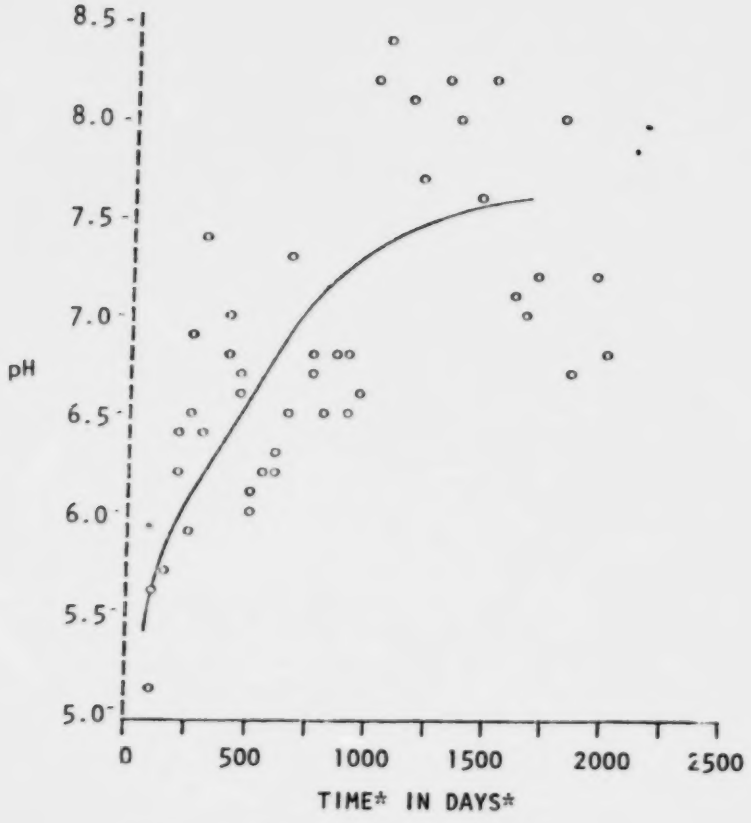


FIGURE 8. COLUMN B - pH
BOTTOM LEACHATE

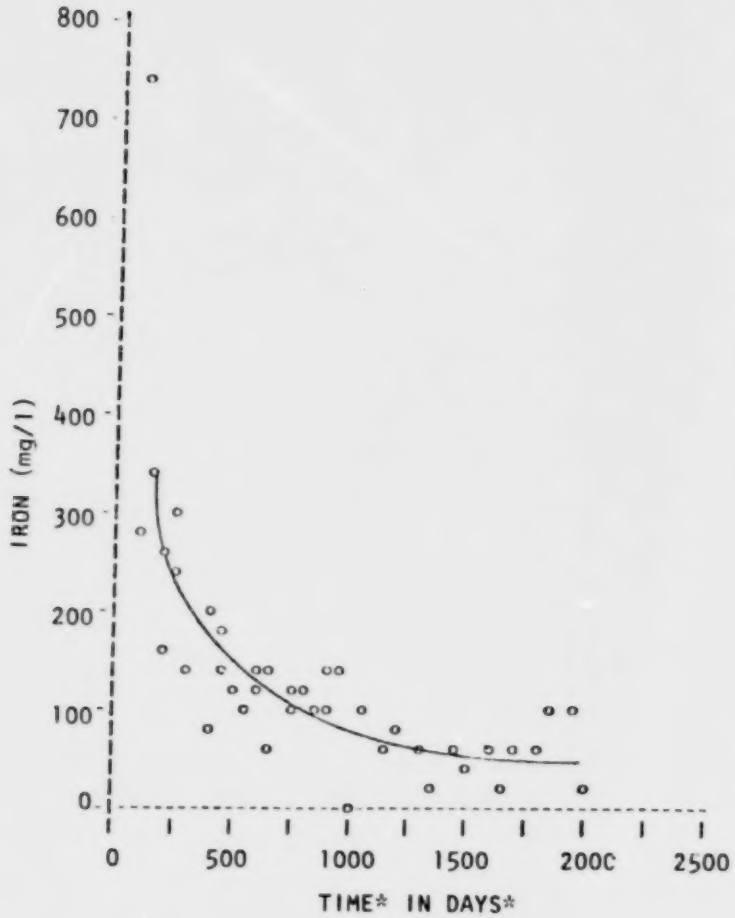


FIGURE 9. COLUMN B - IRON CONCENTRATION
BOTTOM LEACHATE

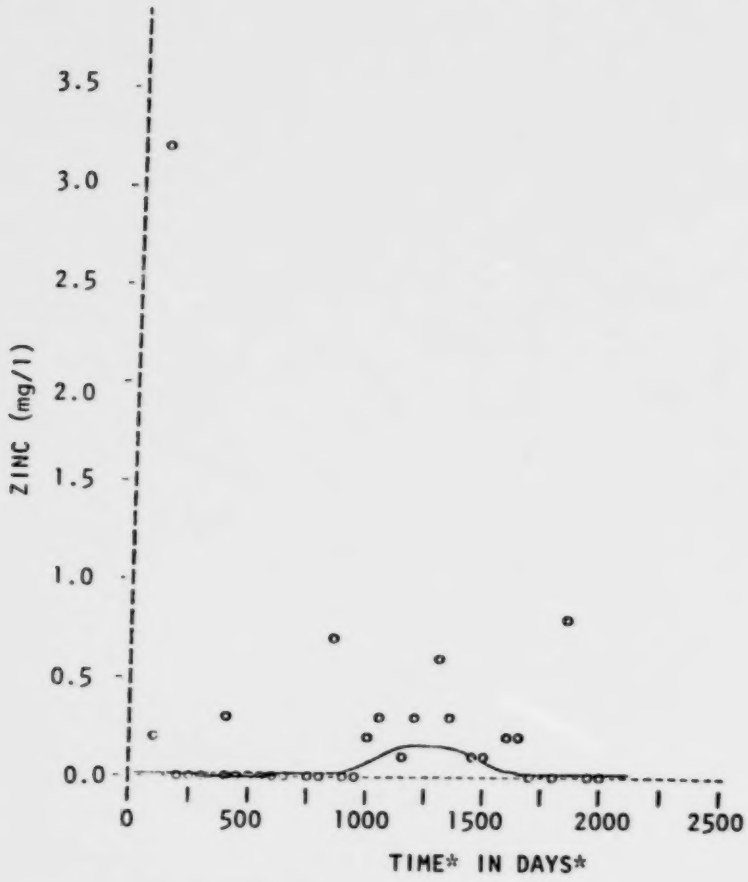


FIGURE 10. COLUMN B - ZINC CONCENTRATION
BOTTOM LEACHATE

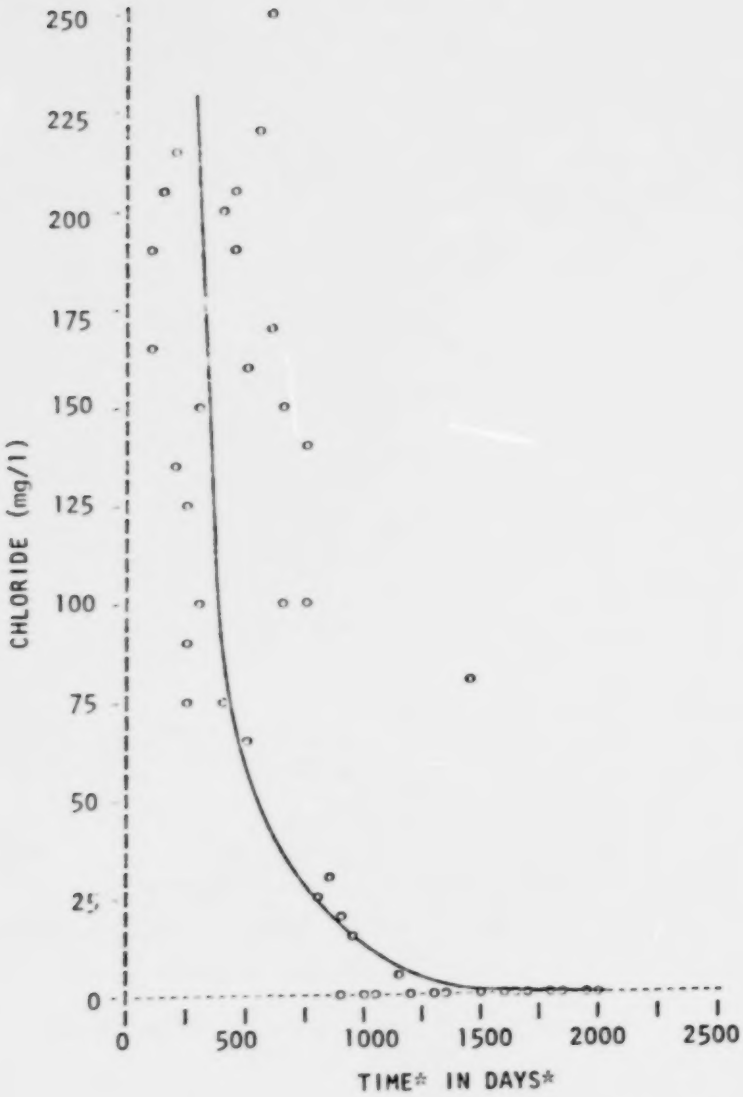


FIGURE 11. COLUMN B - CHLORIDE CONCENTRATION
BOTTOM LEACHATE

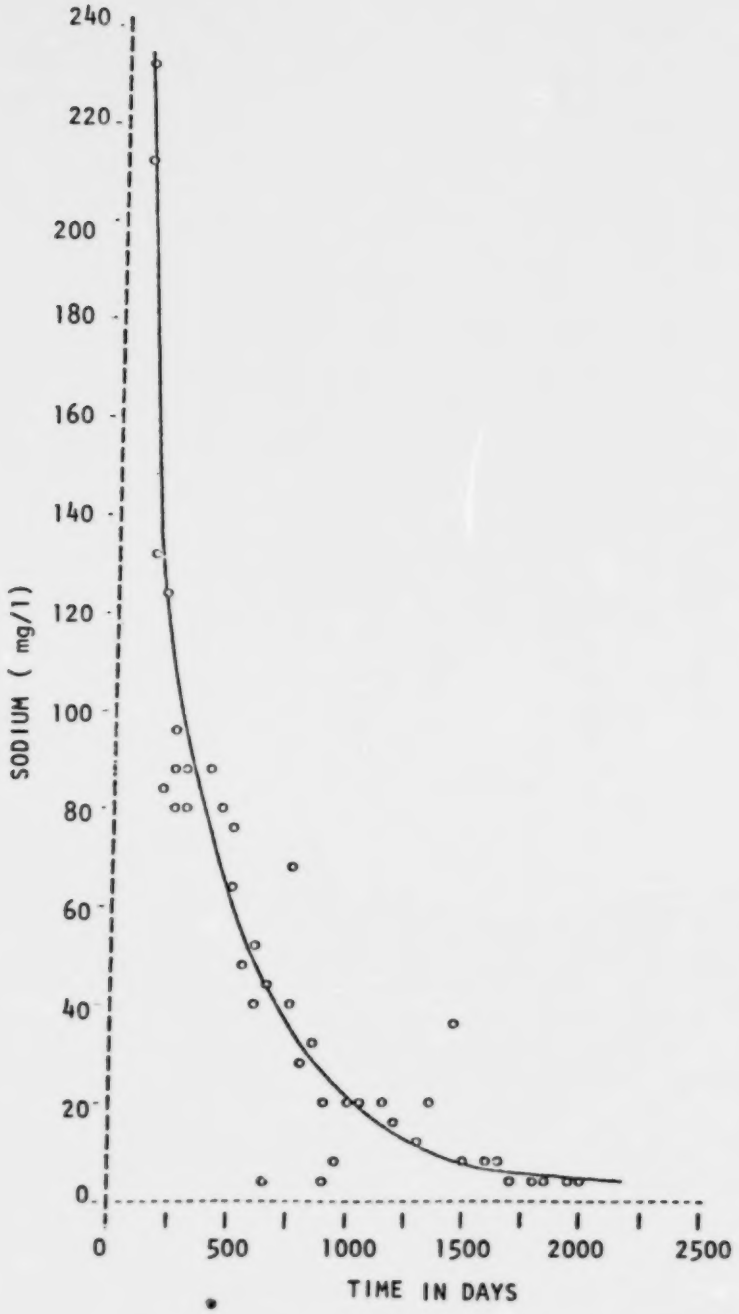


FIGURE 12. COLUMN B - SODIUM CONCENTRATION
BOTTOM LEACHATE

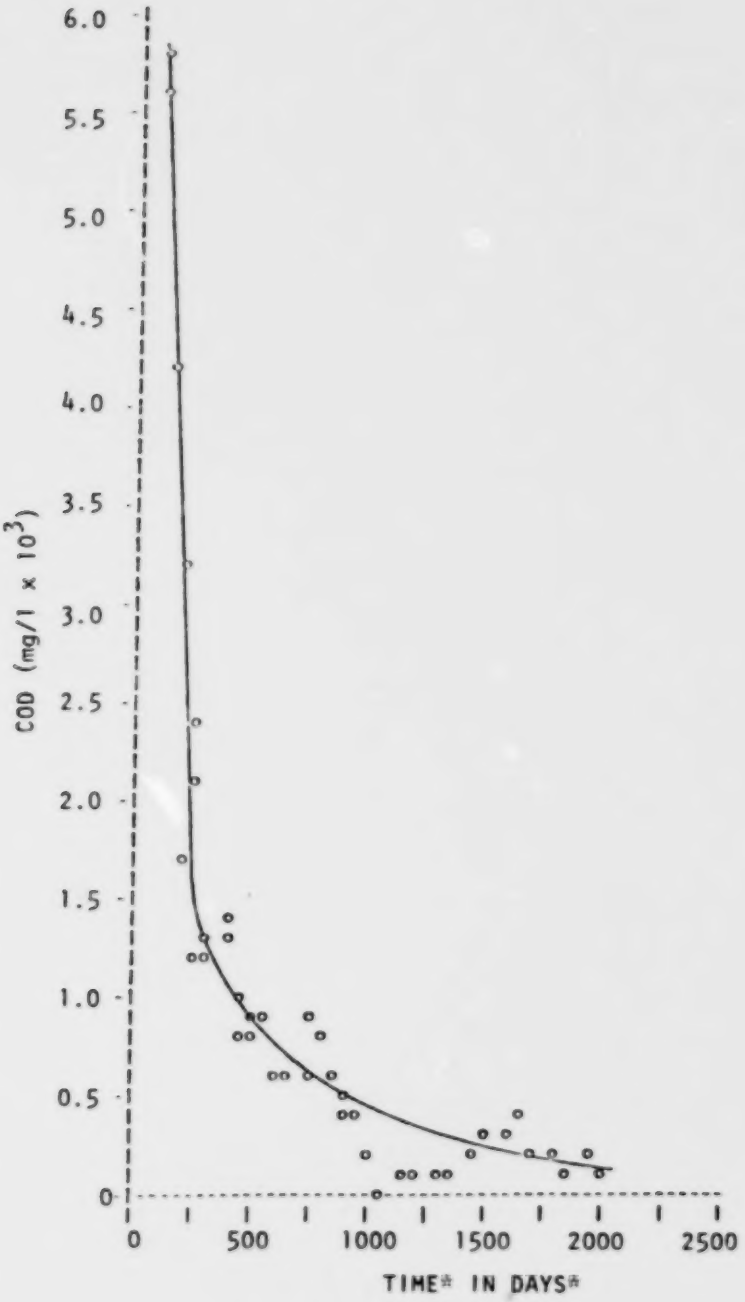


FIGURE 13. COLUMN B - COD CONCENTRATION
BOTTOM LEACHATE

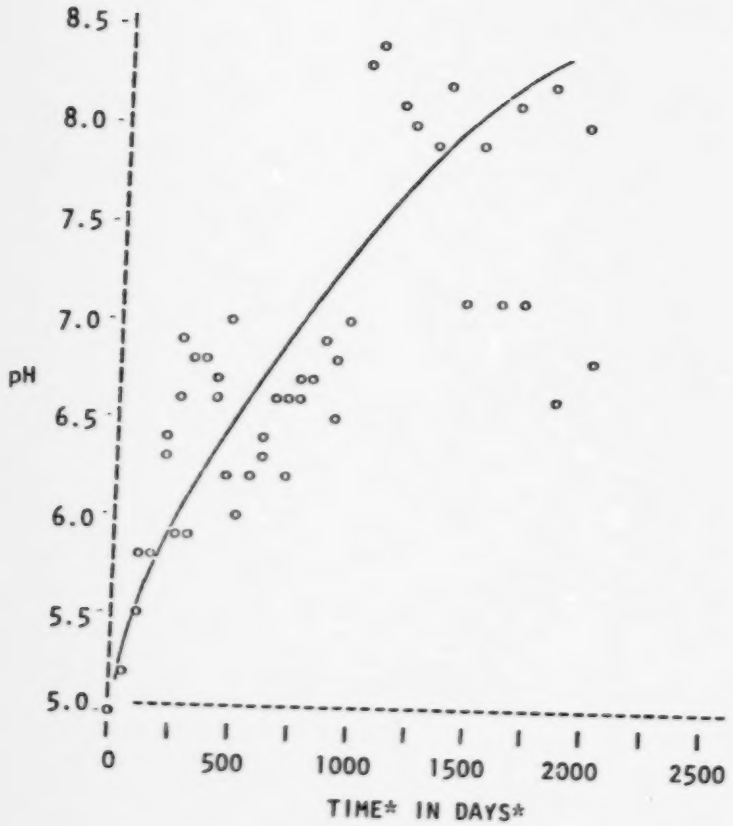


FIGURE 14. COLUMN C - pH
BOTTOM LEACHATE

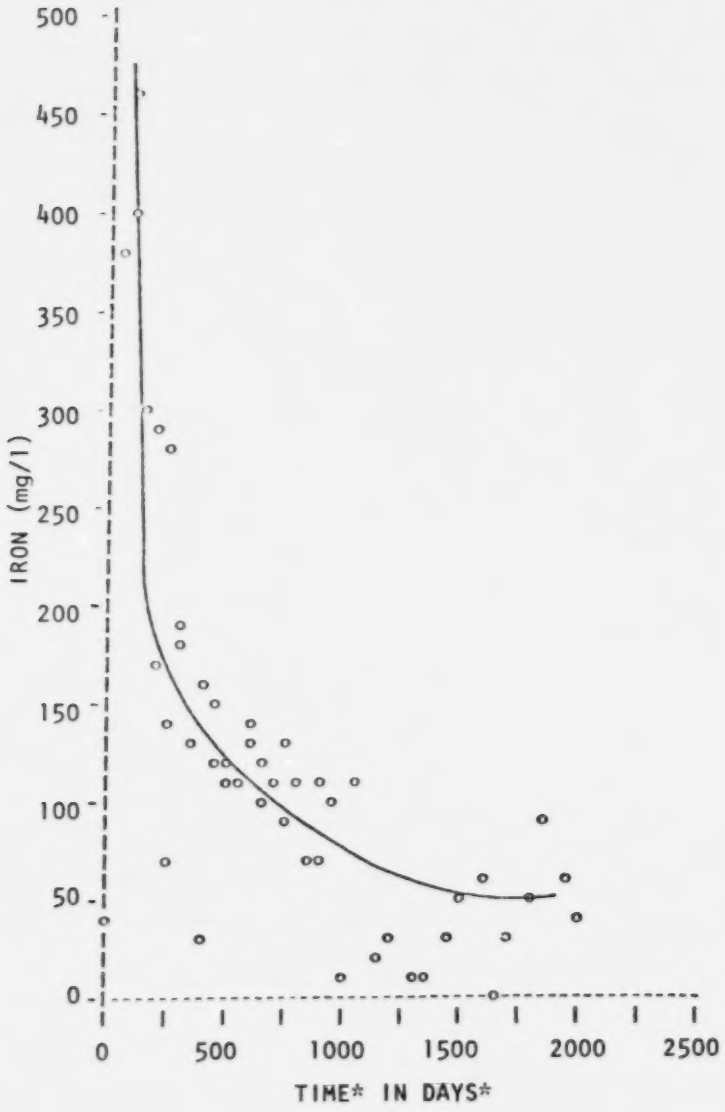


FIGURE 15. COLUMN C - IRON CONCENTRATION
BOTTOM LEACHATE

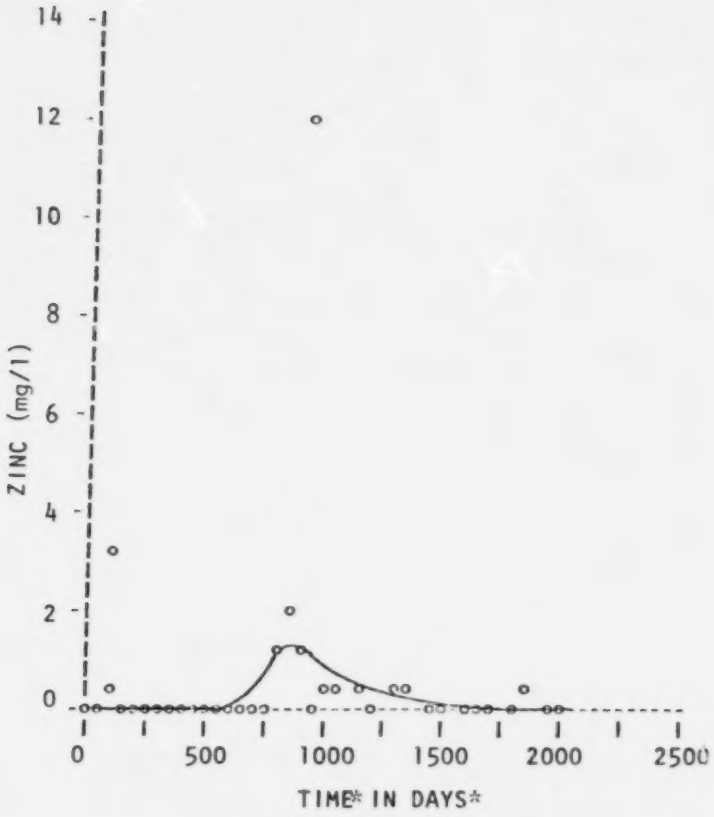


FIGURE 16. COLUMN C - ZINC CONCENTRATION
BOTTOM LEACHATE

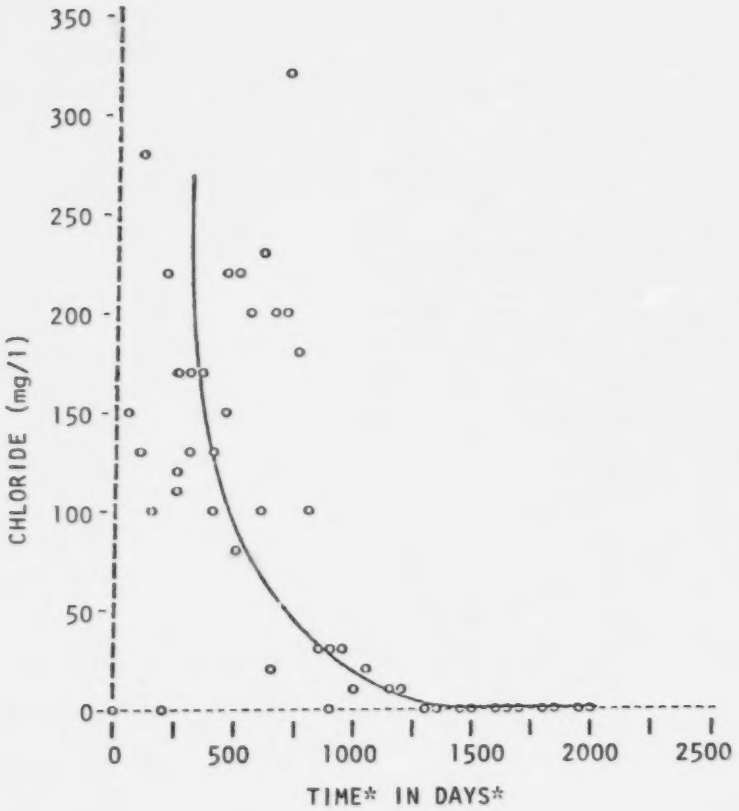


FIGURE 17. COLUMN C - CHLORIDE CONCENTRATION
BOTTOM LEACHATE

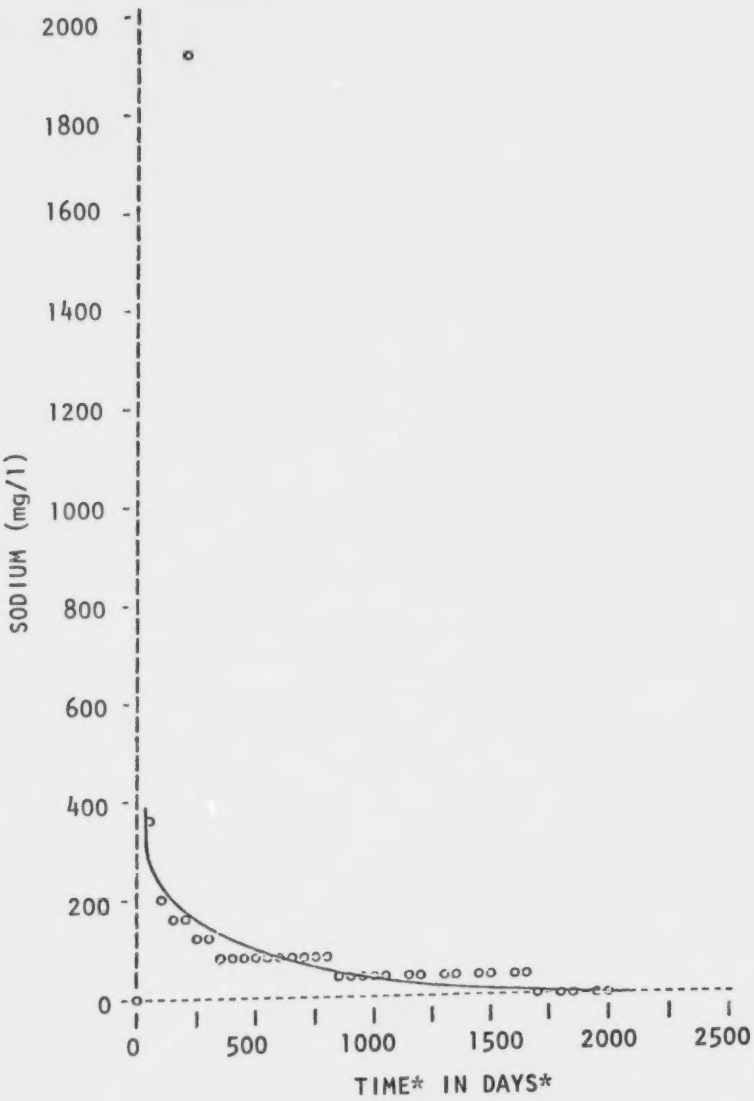


FIGURE 18. COLUMN C - SODIUM CONCENTRATION
BOTTOM LEACHATE

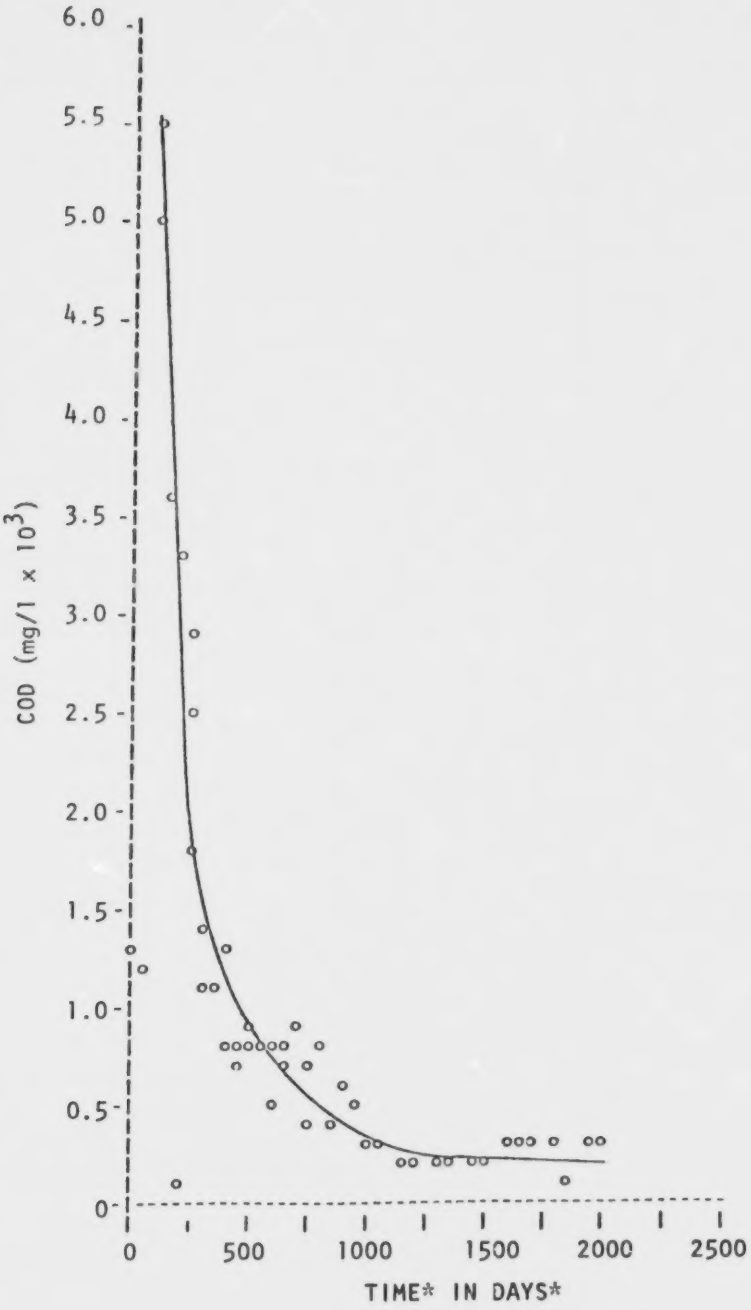


FIGURE 19. COLUMN C - COD CONCENTRATION
BOTTOM LEACHATE

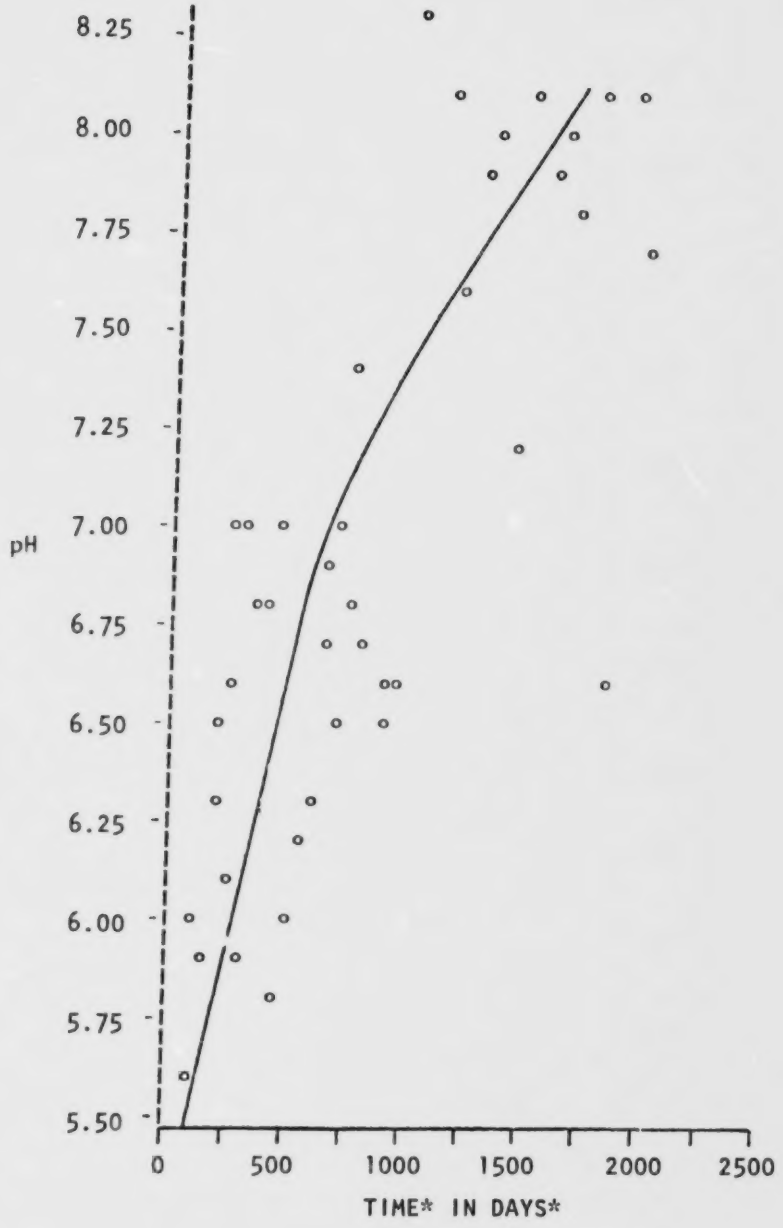


FIGURE 20. COLUMN D - pH
BOTTOM LEACHATE

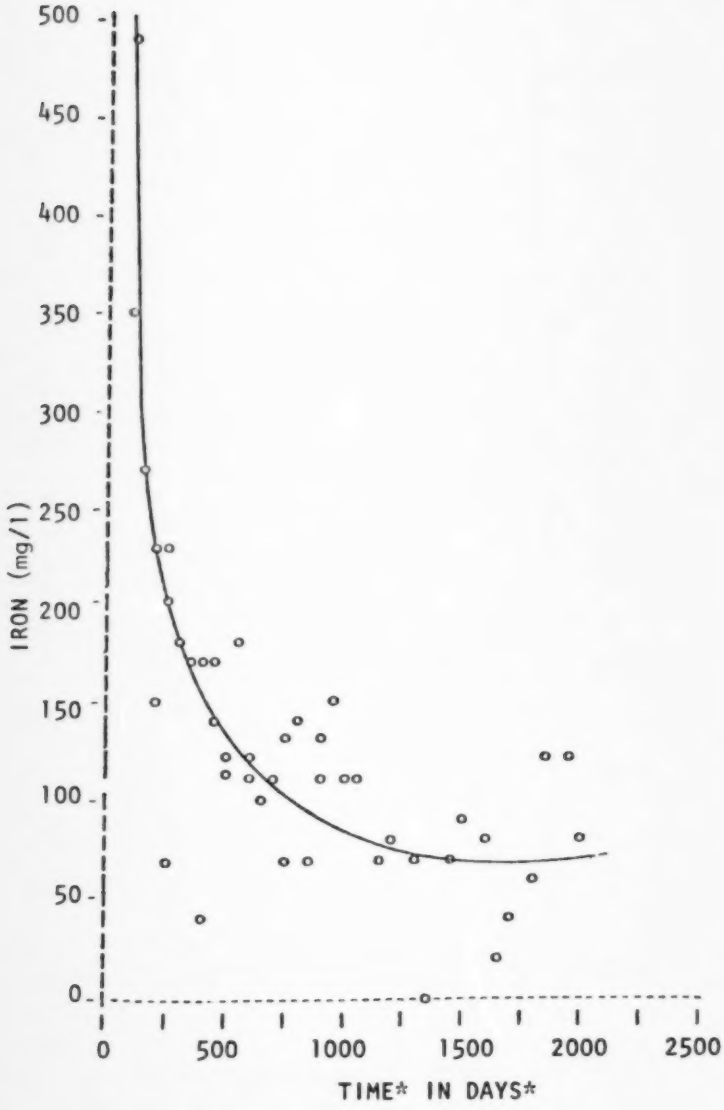


FIGURE 21. COLUMN D - IRON CONCENTRATION
BOTTOM LEACHATE

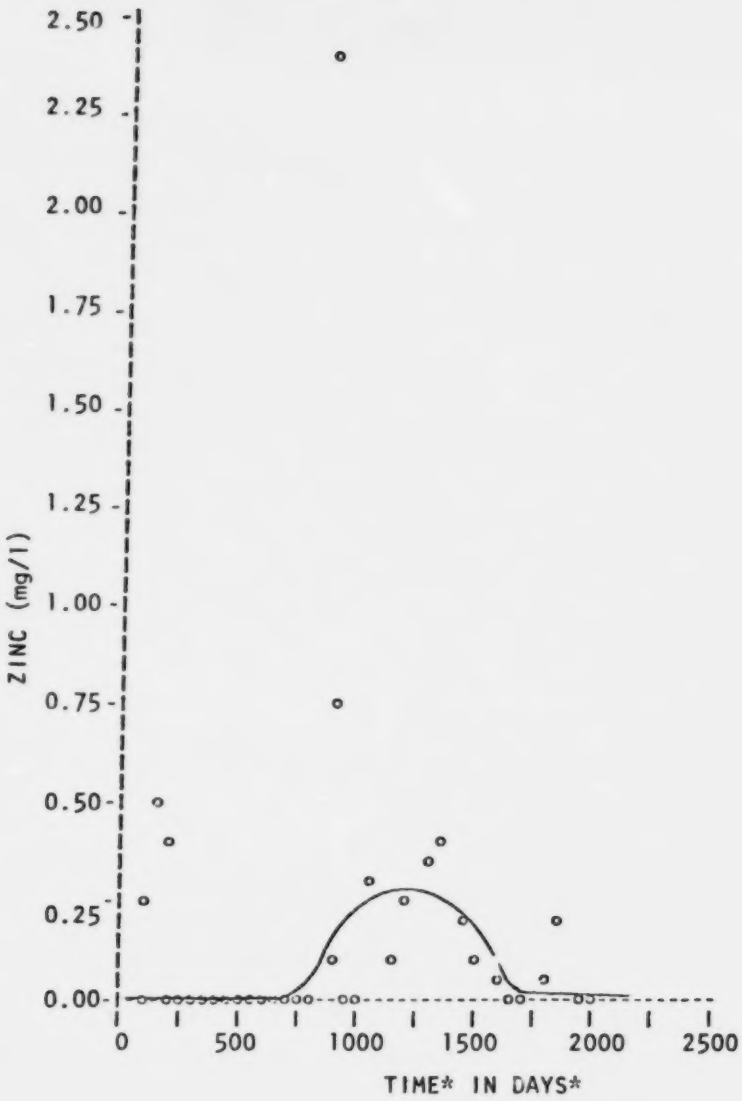


FIGURE 22. COLUMN D - ZINC CONCENTRATION
BOTTOM LEACHATE

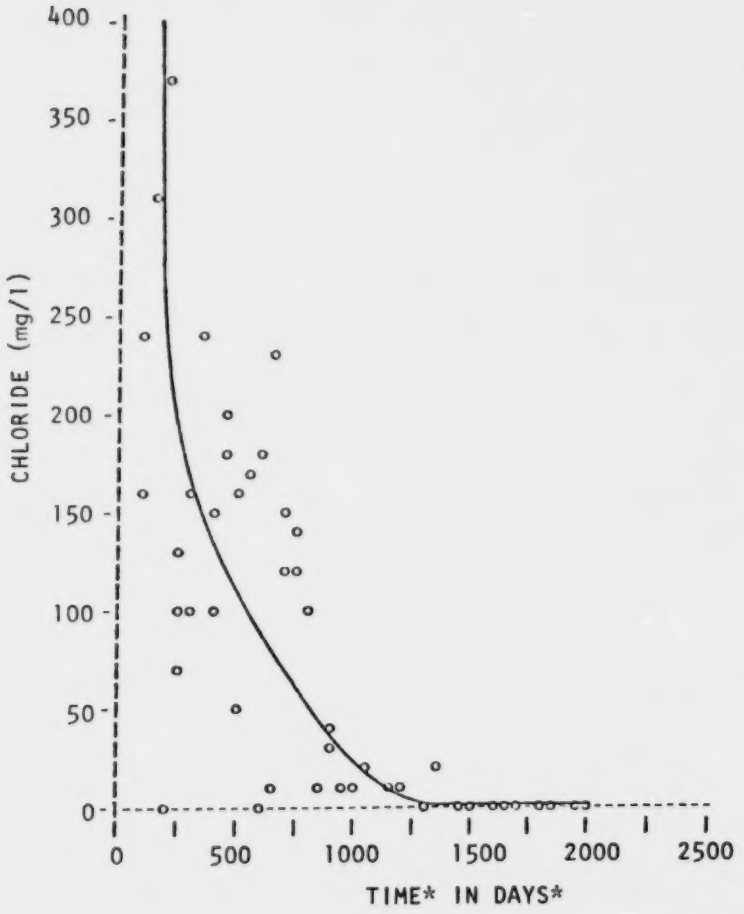


FIGURE 23. COLUMN D - CHLORIDE CONCENTRATION
BOTTOM LEACHATE

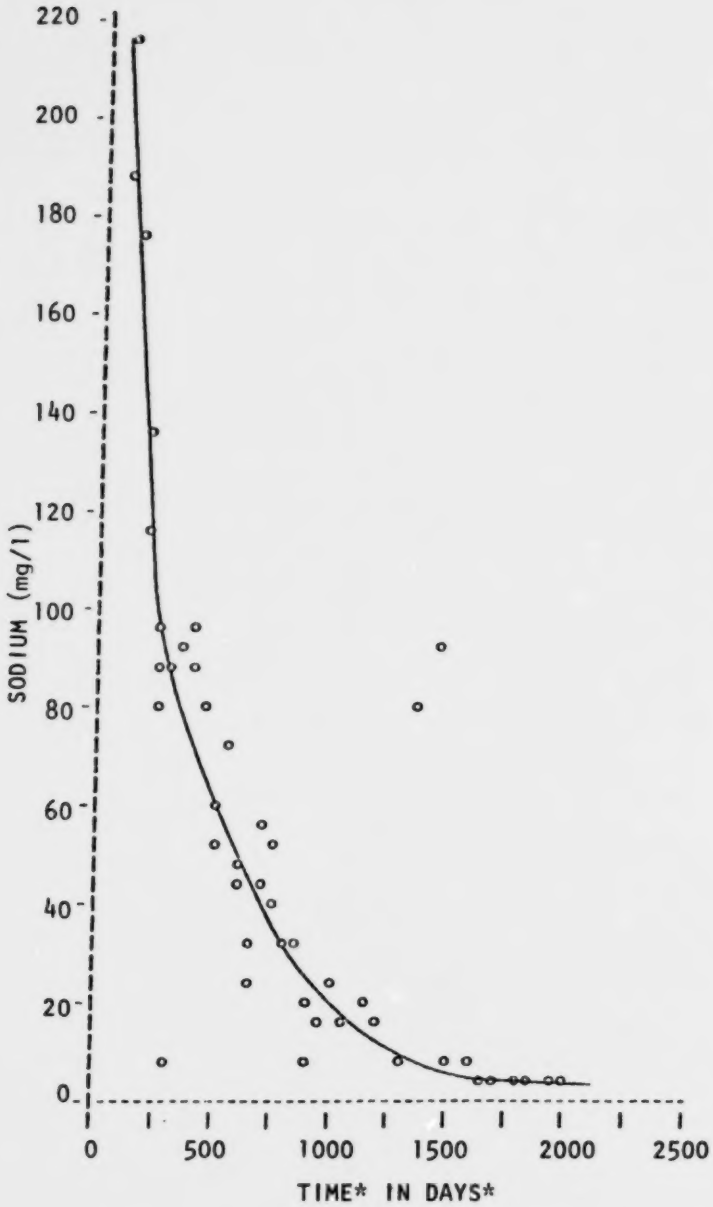


FIGURE 24. COLUMN D - SODIUM CONCENTRATION
BOTTOM LEACHATE

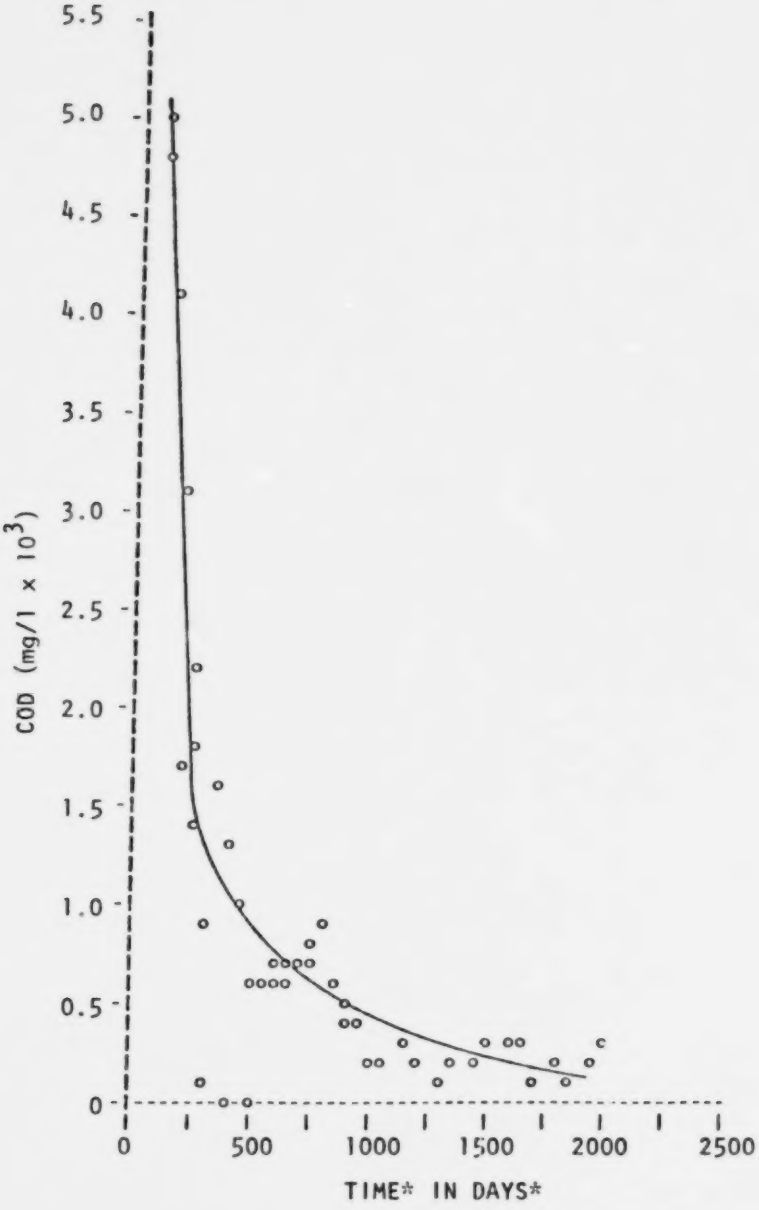


FIGURE 25. COLUMN D - COD CONCENTRATION
BOTTOM LEACHATE

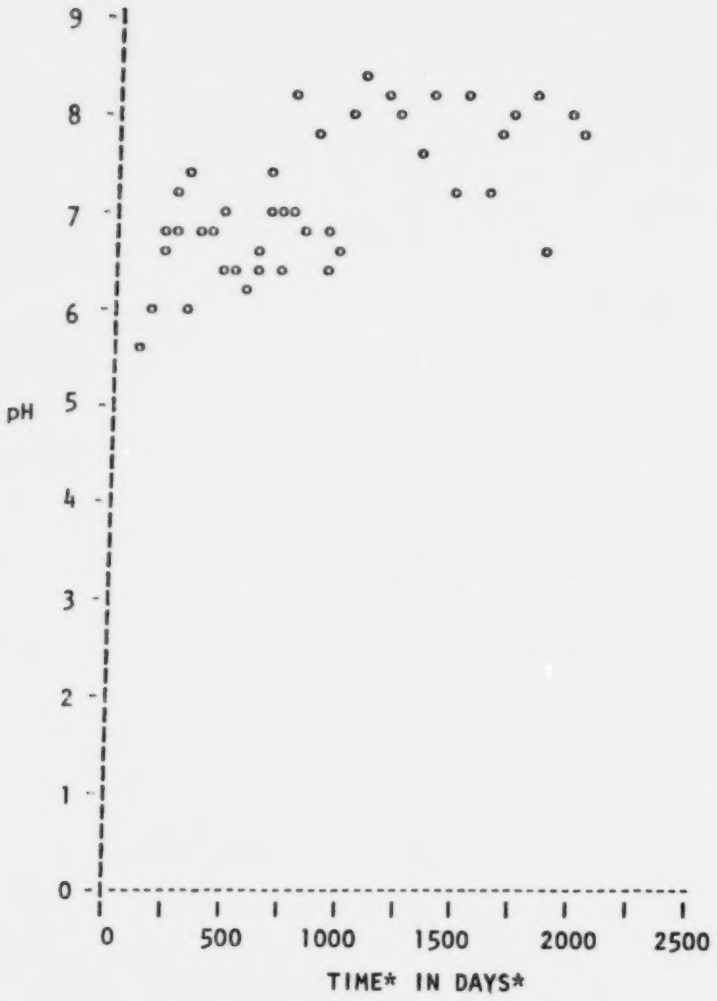


FIGURE 26. COLUME D6 - LEACHATE pH

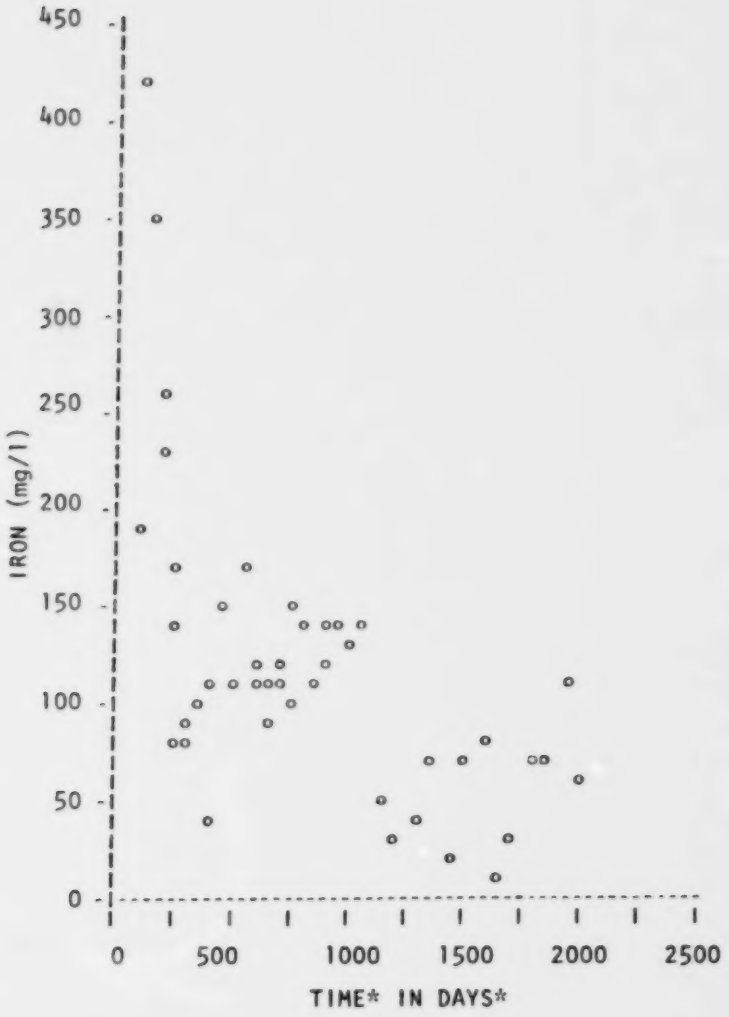


FIGURE 27. COLUMN D6 - LEACHATE IRON

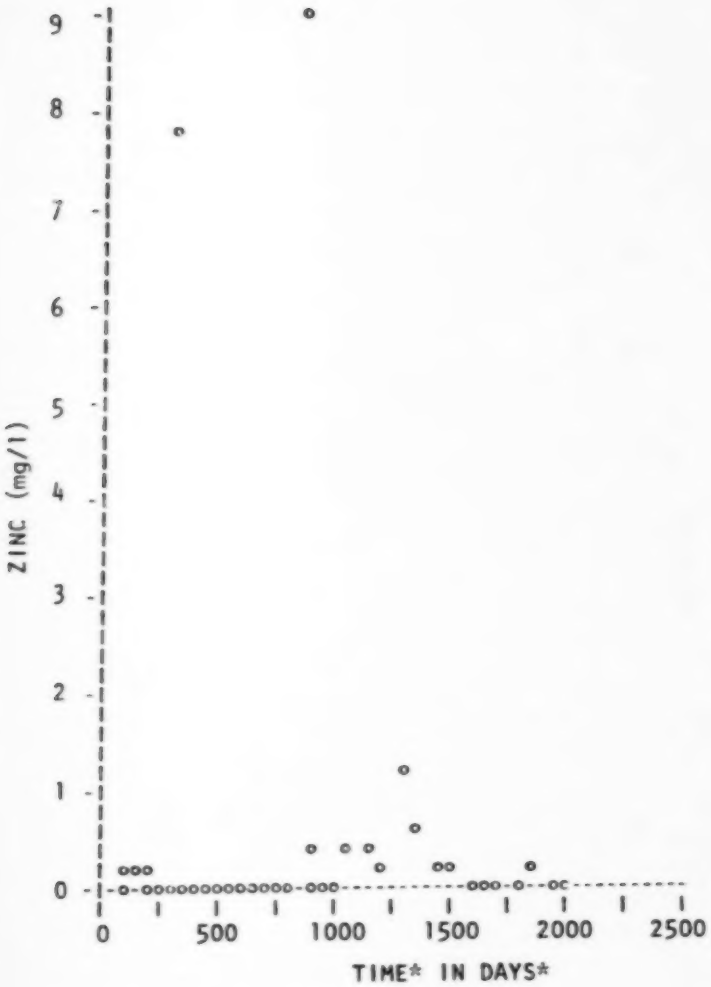


FIGURE 28. COLUMN D6 - LEACHATE ZINC

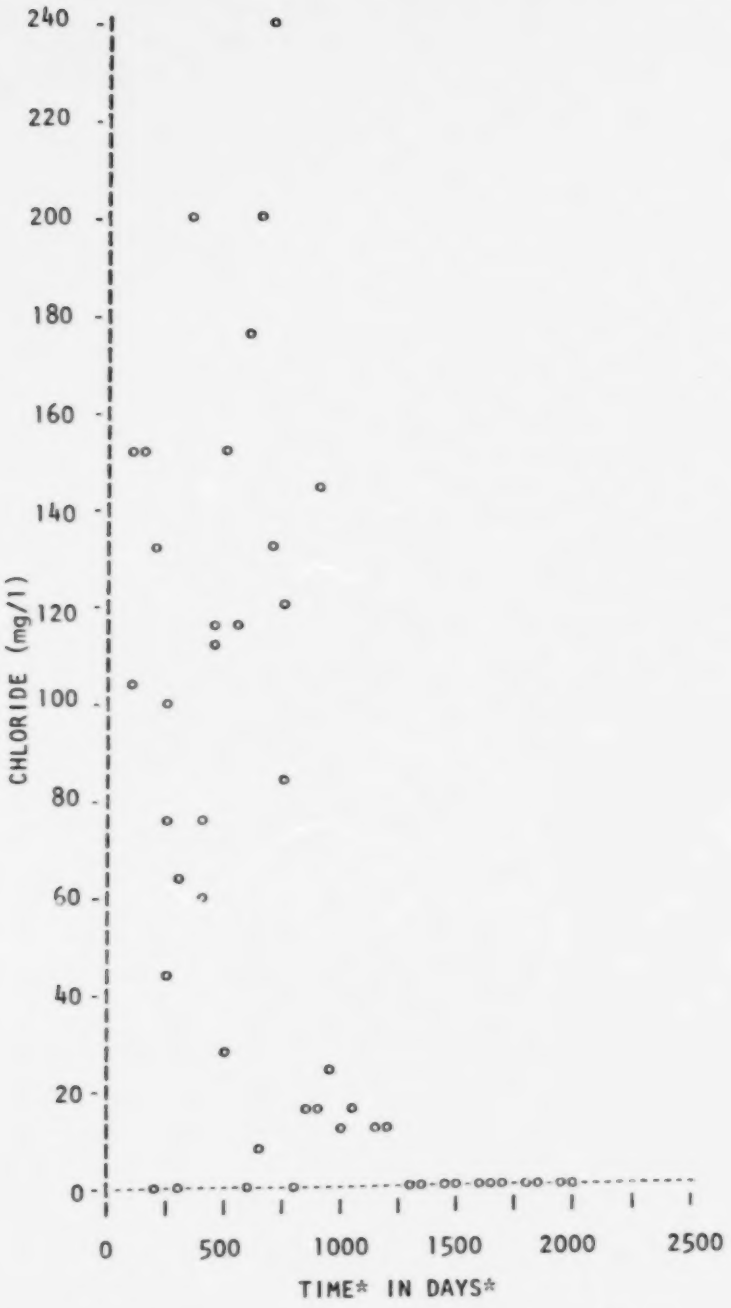


FIGURE 29. COLUMN D6 - LEACHATE CHLORIDE

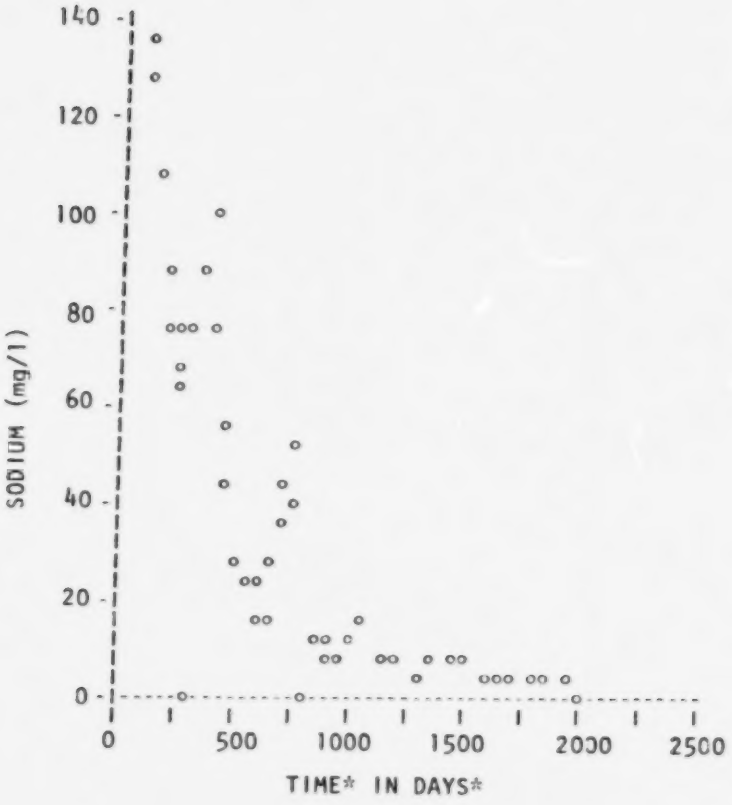


FIGURE 30. COLUMN D6 - LEACHATE SODIUM

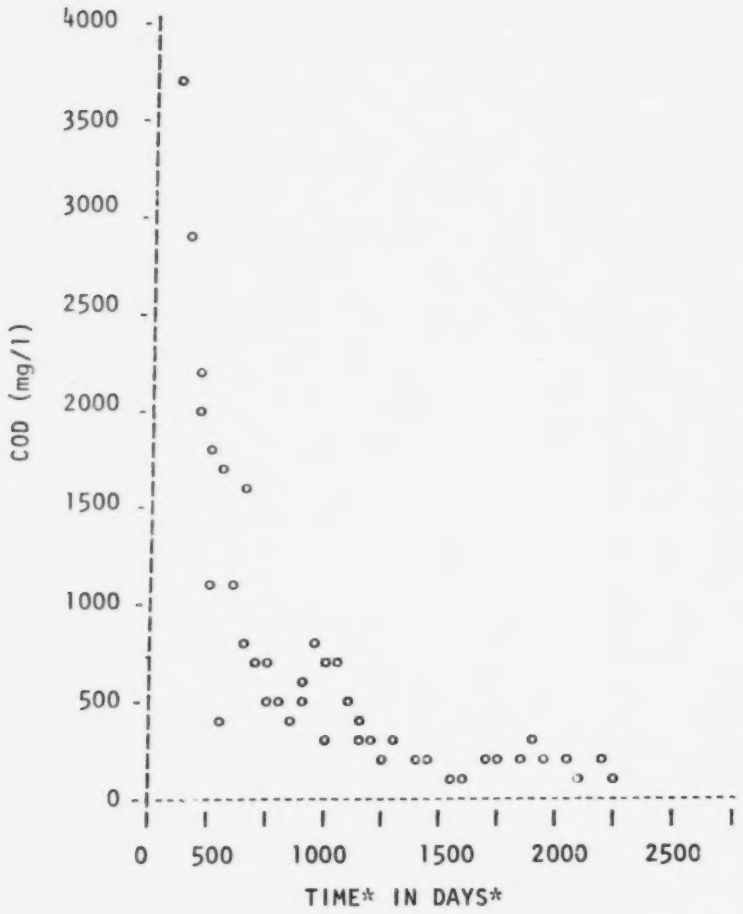


FIGURE 31. COLUMN D6 - LEACHATE COD

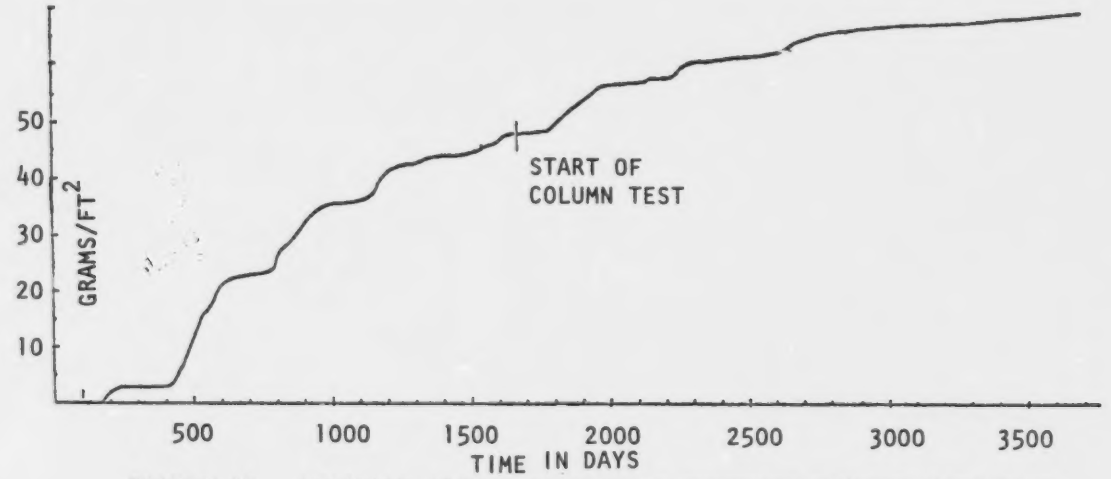


FIGURE 32. LEACHATE IRON - CUMULATIVE QUANTITY REMOVED WITH TIME

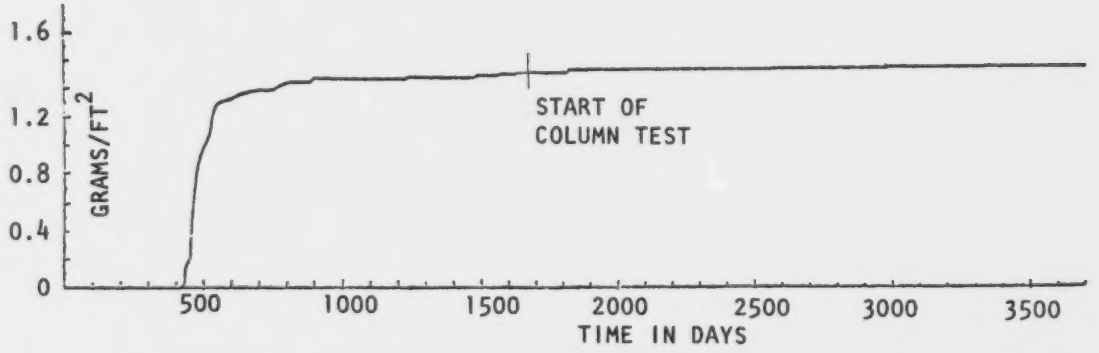


FIGURE 33. LEACHATE ZINC - CUMULATIVE QUANTITY REMOVED WITH TIME

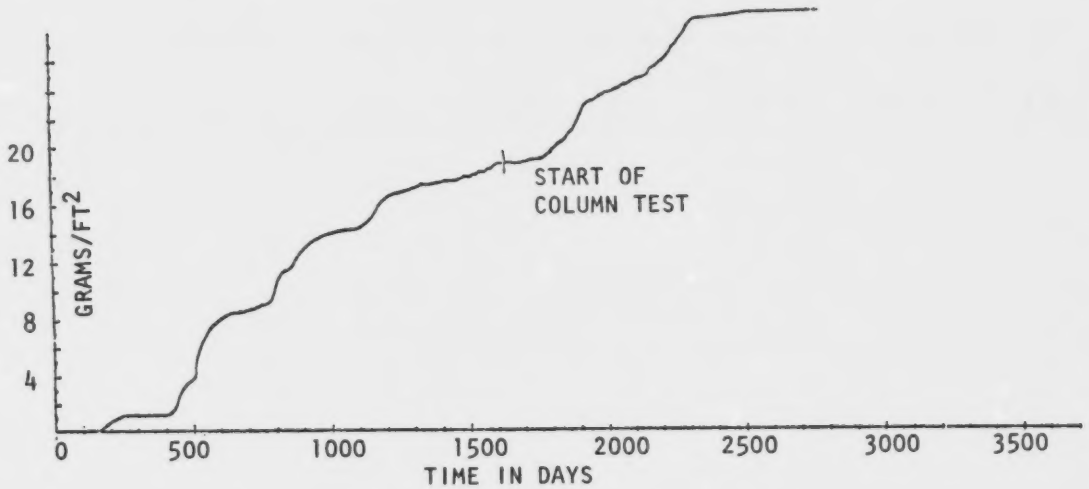


FIGURE 34. CHLORIDE - CUMULATIVE QUANTITY REMOVED WITH TIME

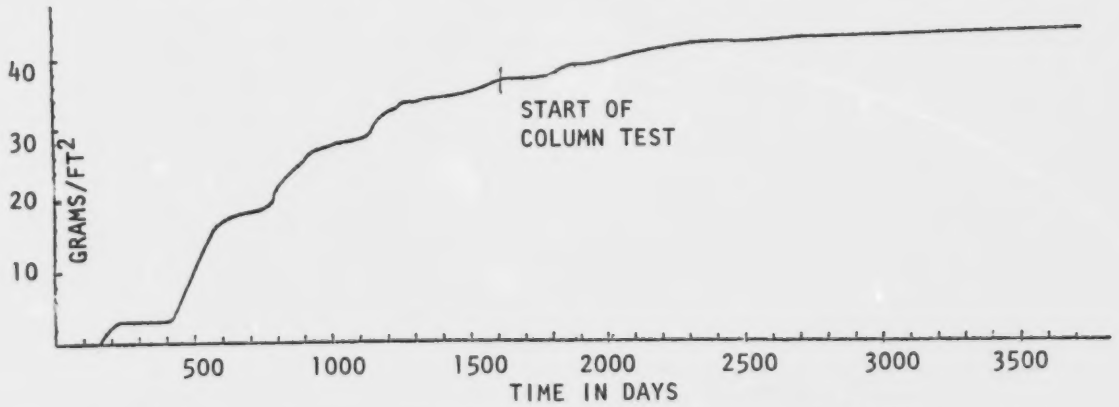


FIGURE 35. SODIUM - CUMULATIVE QUANTITY REMOVED WITH TIME

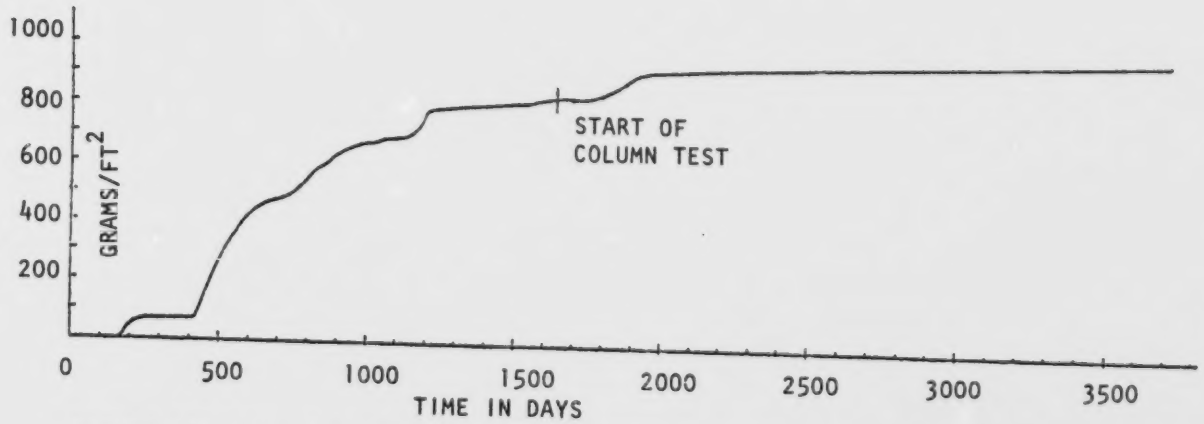


FIGURE 36. CHEMICAL OXYGEN DEMAND - CUMULATIVE QUANTITY REMOVED WITH TIME

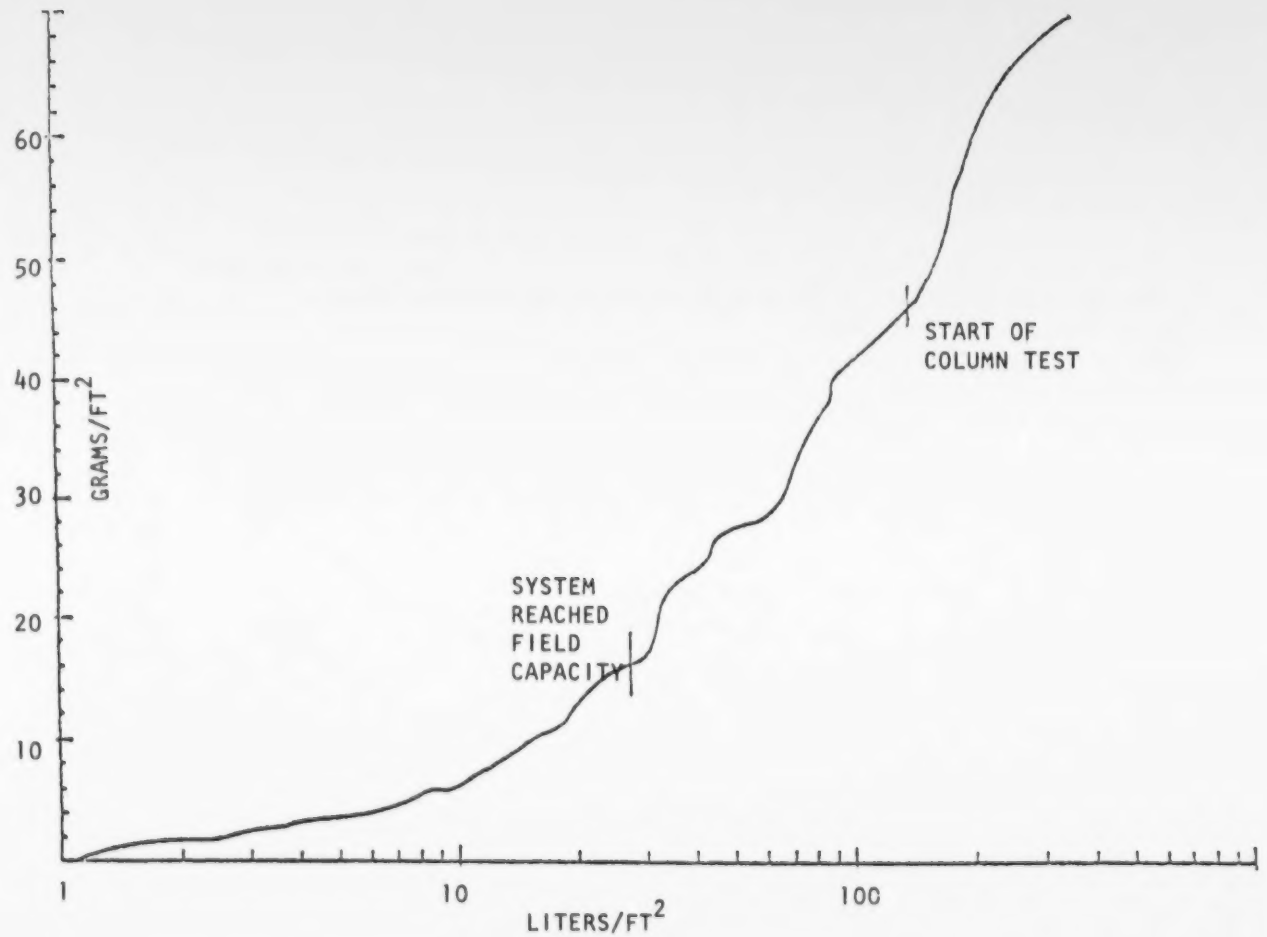


FIGURE 37. LEACHATE IRON - CUMULATIVE GRAMS/FT^2 vs. QUANTITY OF LEACHATE/FT^2

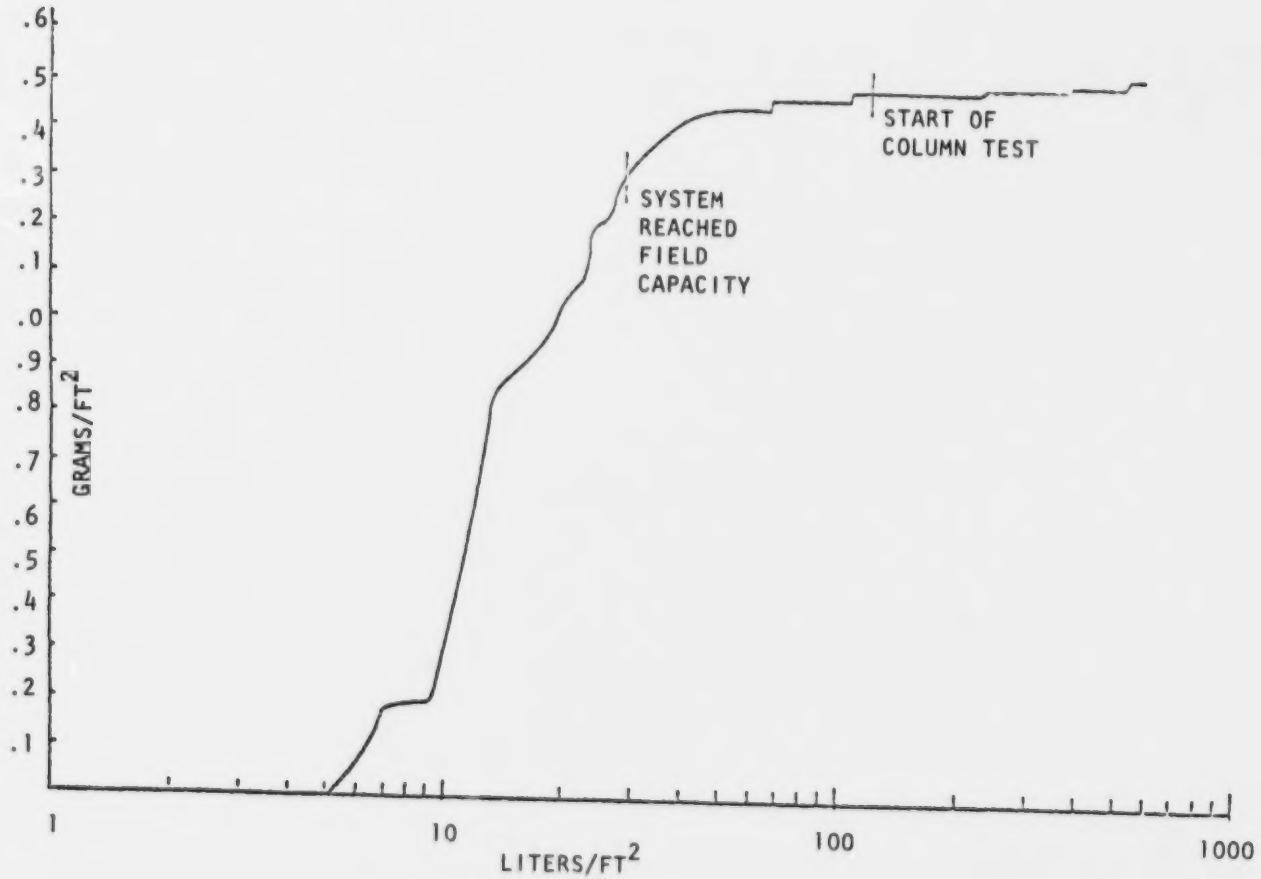


FIGURE 38. ZINC - CUMULATIVE GRAMS/FT^2 REMOVED vs. QUANTITY OF LEACHATE/FT^2

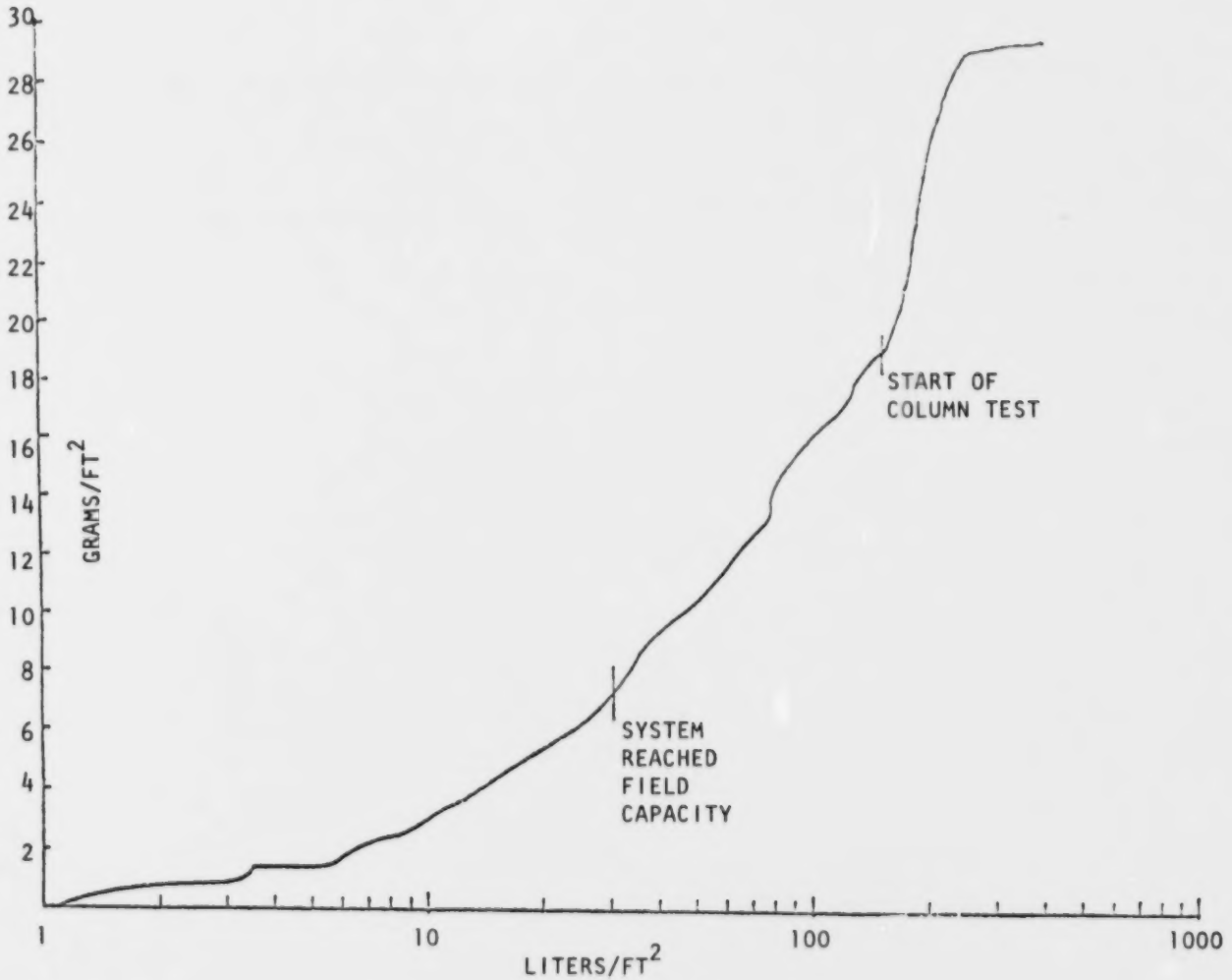


FIGURE 39. CHLORIDE - CUMULATIVE GRAMS/FT^2 REMOVED vs. QUANTITY OF LEACHATE/FT^2

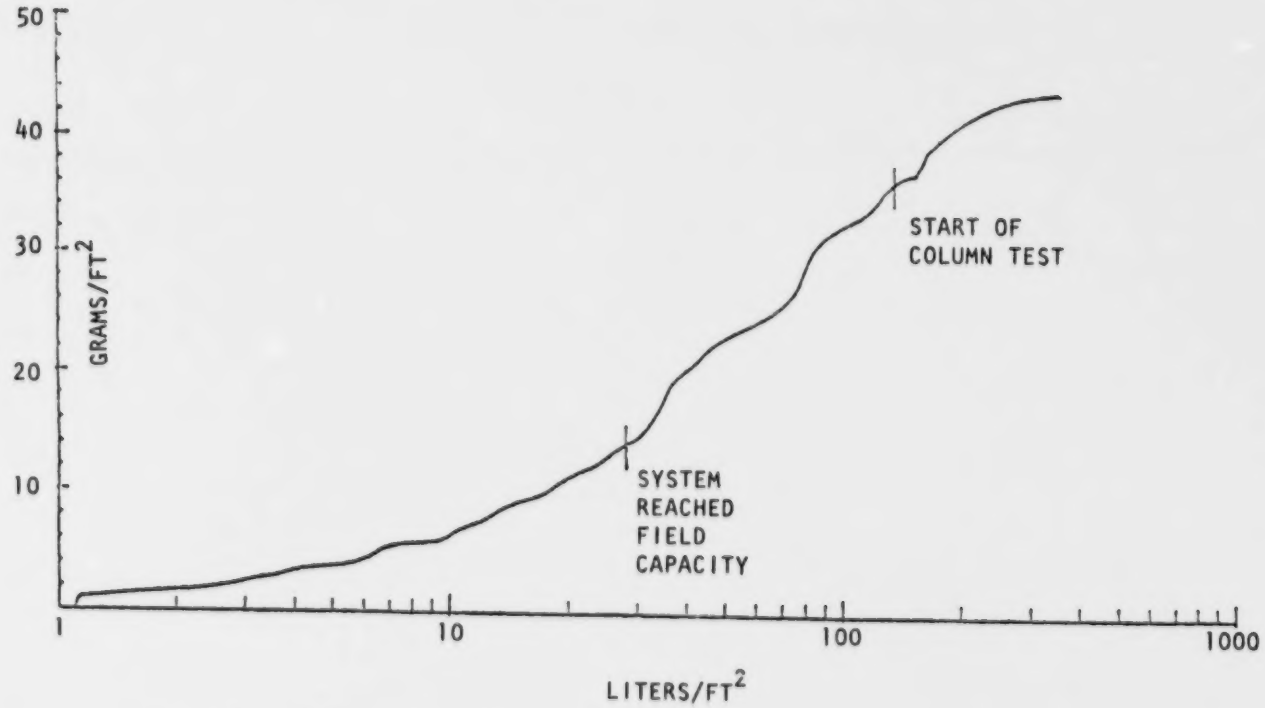


FIGURE 40. SODIUM - CUMULATIVE GRAMS/FT^2 REMOVED vs. QUANTITY OF LEACHATE/FT^2

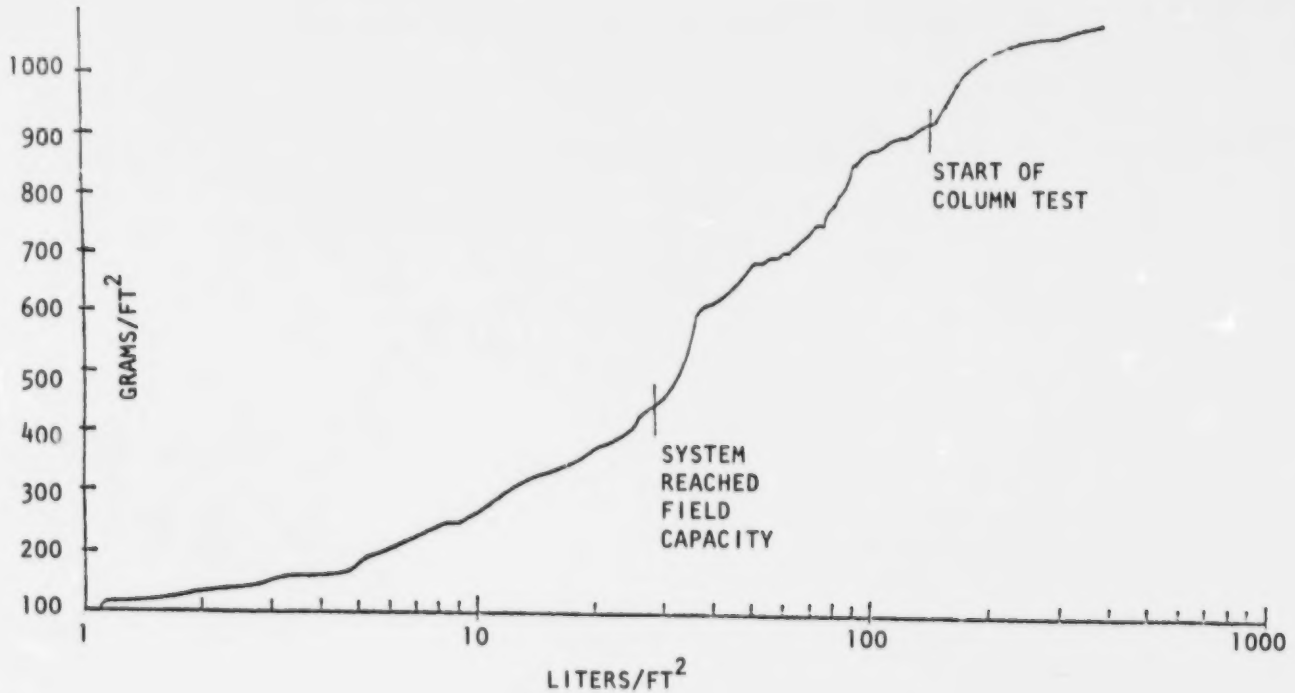


FIGURE 41. CHEMICAL OXYGEN DEMAND - CUMULATIVE GRAMS/FT^2 REMOVED vs. QUANTITY OF LEACHATE/FT^2

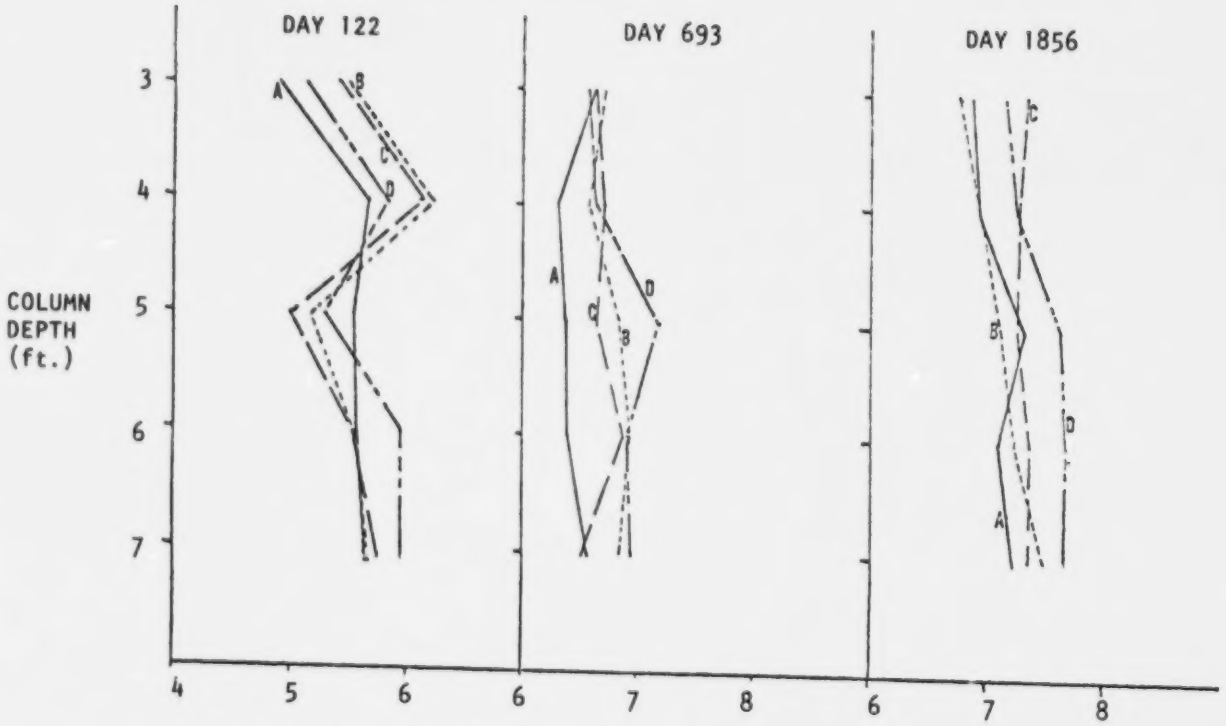


FIGURE 42. PLEXIGLAS COLUMN PROFILES. COLUMNS A, B, C & D

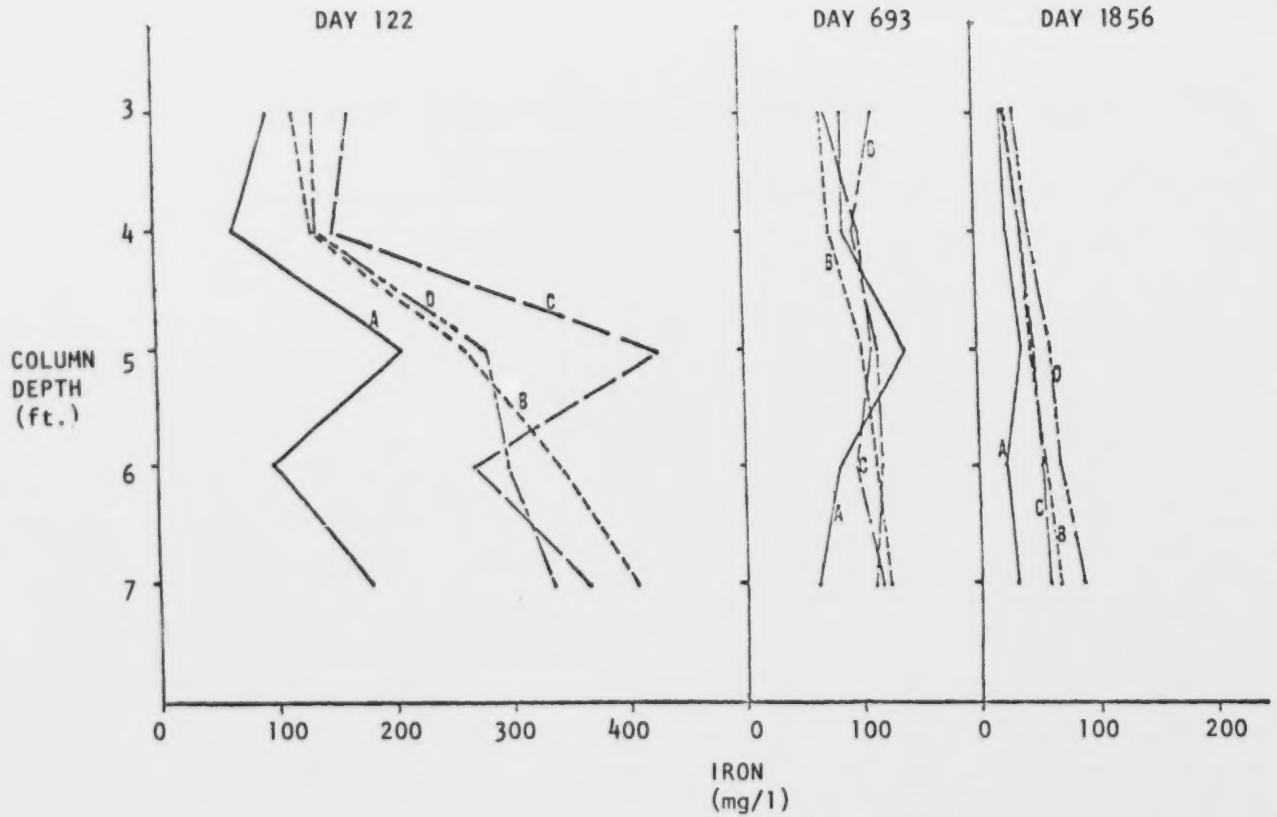


FIGURE 43. PLEXIGLAS COLUMN PROFILES. COLUMNS A, B, C & D

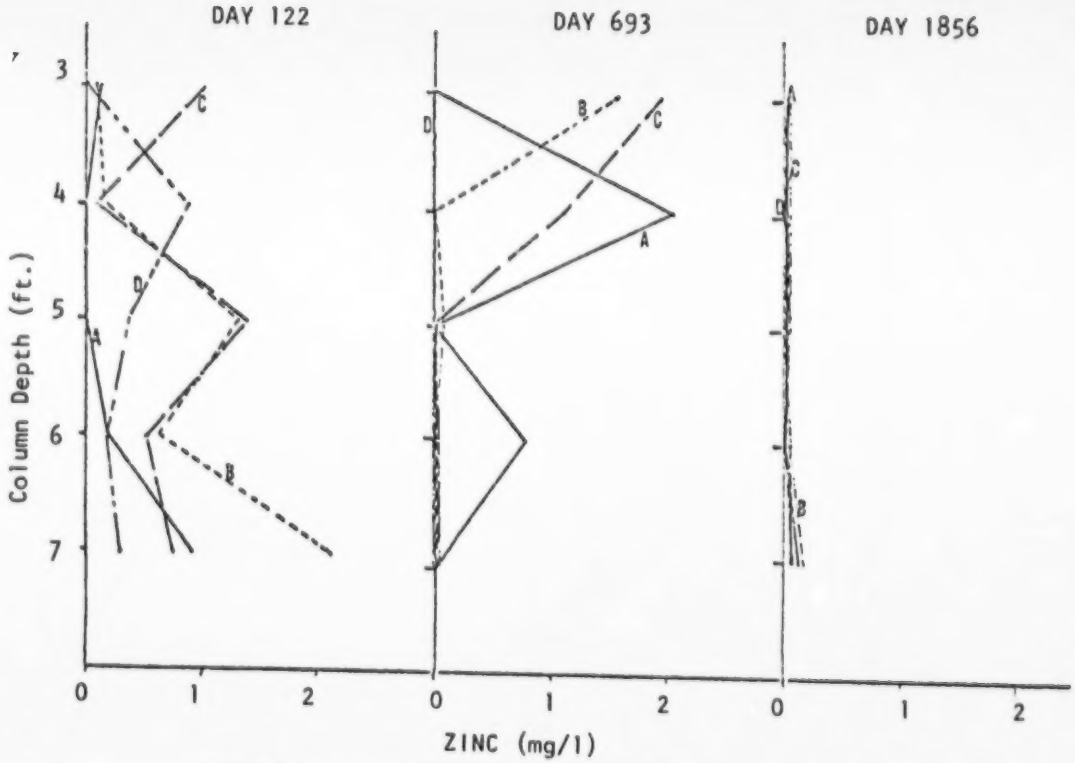


FIGURE 44. PLEXIGLAS COLUMN PROFILES. COLUMNS A, B, C & D

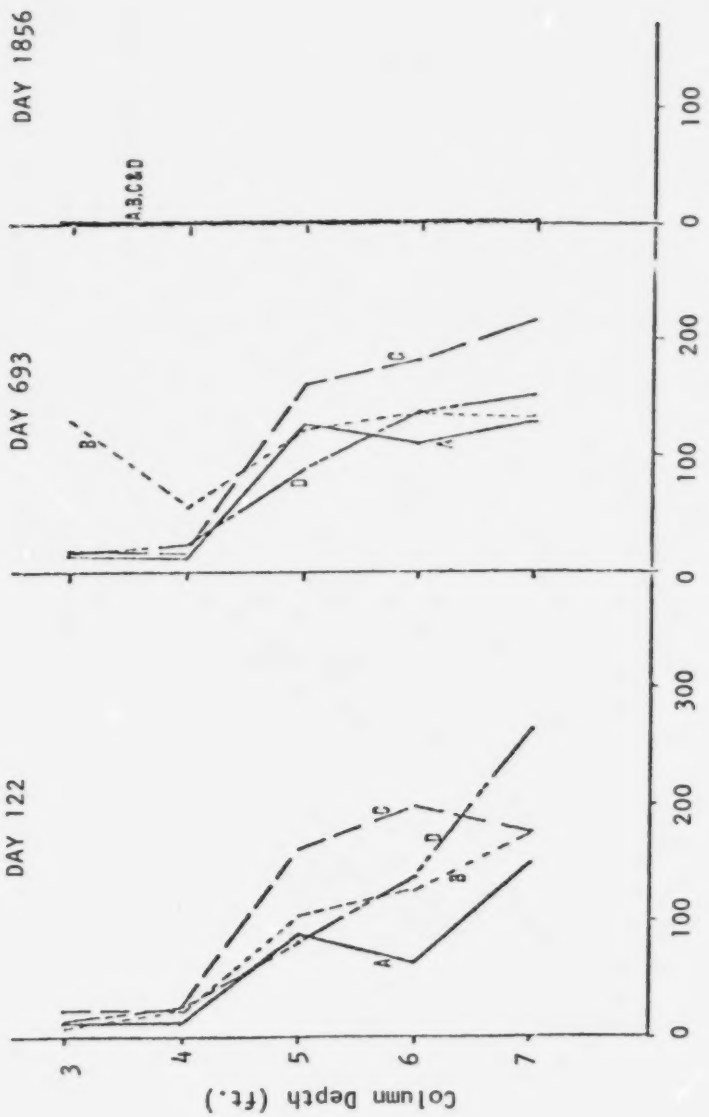


FIGURE 45. PLEXIGLAS COLUMN PROFILES. COLUMNS A, B, C & D

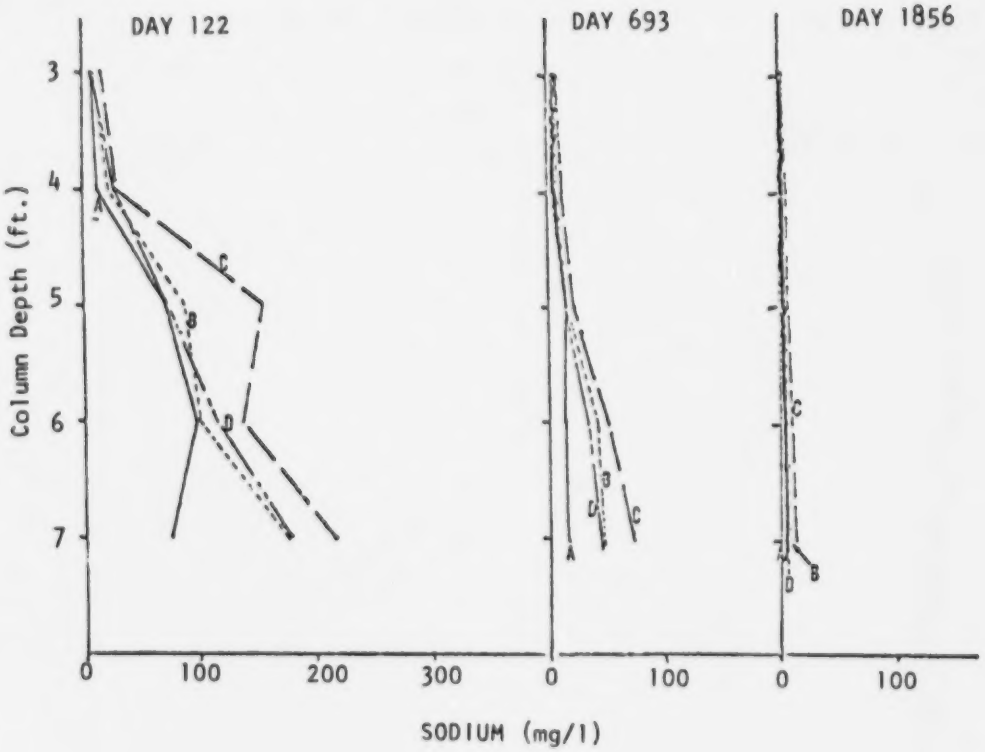


FIGURE 46. PLEXIGLAS COLUMN PROFILES. COLUMNS A, B, C & D

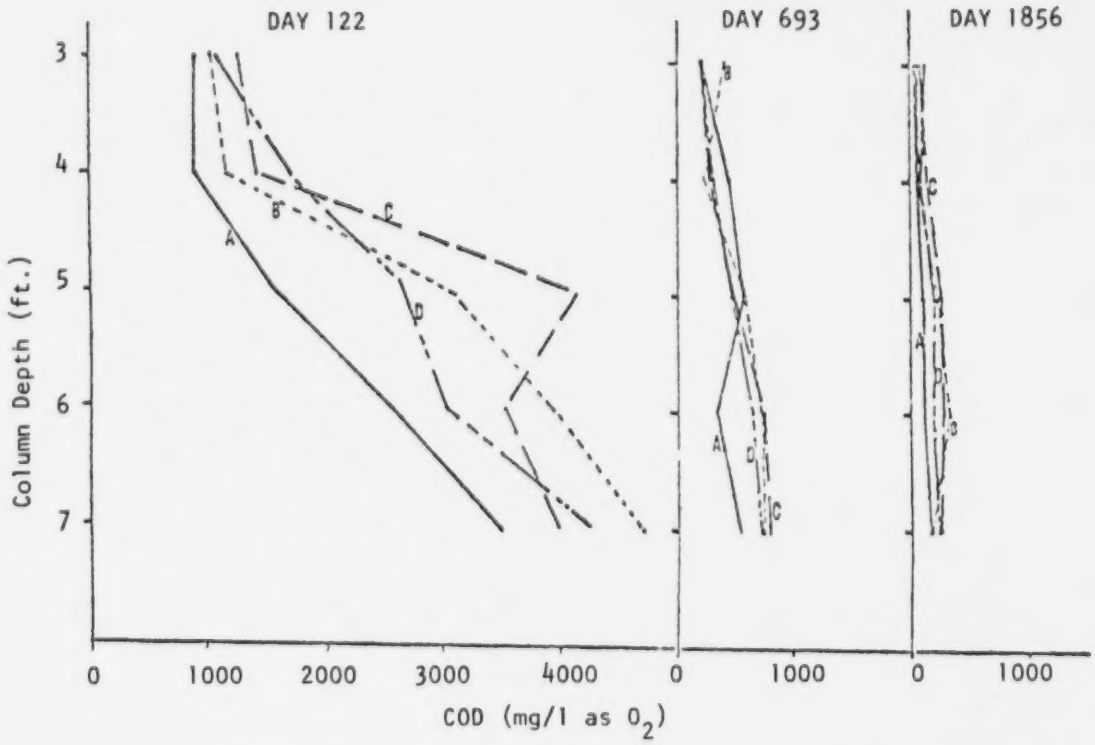


FIGURE 47. PLEXIGLAS COLUMN PROFILES. COLUMNS A, B, C & D

The addition of the column time span to the lysimeter data presented in the Final Report gives approximately ten (10) years of leachate generation data.

pH

Figure 2 presents the leachate contaminant data for the leachate from section 7 of Column A.

The pH curve, Figure 2, shows that the leachate was initially acid with increasing values until about 1000 DAYS* into the test. After that time the leachate became basic and appeared to approach a pH of 8.0. A similar behavior pattern was obtained for Column B (Figure 8). In Column C (Figure 14) and Column D (Figure 20), while a pH of 8.0 was approached asymptotically, a pH of 7 was reached approximately 250 DAYS* in the period. For Column "C" the difference can only be attributed to the difference in its feeding program from Columns "A" and "B". For Column "D", the differences could be attributed to nutrient effect when compared to "A" and "B", but the cause of its similarity to "C" is not readily apparent.

A more meaningful comparison of pH for each column with depth is presented in Figure 42. The results shown are for three different DAYS". As shown, while pH values do differ with depth and column, there is no uniqueness to the curve patterns or trends. However, most important is that by DAY* 1856 all pH values are approaching the same values.

Iron

The iron curves for the four (4) columns, (Figures 3, 9, 15 and 21) show similar decreasing patterns toward minimal, if not zero, concentration levels. The curve for Column A (Figure 3) shows the most rapid decrease of iron concentration which probably reflects the water feeding program. The column "D" iron curve (Figure 21) shows the slowest decrease of iron concentrations and, in fact, at the end of the test they were still in the 50 to 100 mg/l range, significantly higher than the final concentrations for the other columns.

The iron concentration vertical profile curves for each column are presented in Figure 43. Again, the typical early irregular initial patterns prevail with

a trend toward uniform common curves at DAY* 1856.

Zinc

The zinc curves, Figures 4, 10, 16 and 22, show that in all cases concentrations are low with occasional sudden increases which occurred on a rather random pattern. While concentrations are low for Columns A, B, and C, they are lowest for Column A. Further, the nutrient influence, Figure 22, appears to be a retarding of the reduction of zinc concentrations to negligible levels during the latter period of the study.

The zinc concentration vertical profile curve, Figure 44, shows behavior patterns similar to those described earlier. Overall at DAY* 1856, zinc concentrations in all columns were almost zero except in the bottom section (section 7).

Chloride

Chloride concentration curves for the bottom leachate are presented in Figures 5, 11, 17 and 23. Chloride results showed a large degree of scatter during the early stages of the study. However, concentrations were decreasing. After DAY* 100 all chloride concentrations were virtually zero.

The chloride concentration vertical profile curves, Figure 45, show the typical early TIME* period irregular pattern followed by an almost complete coincidence of all test results toward the termination of the test.

Sodium

Sodium concentration curves for the bottom leachate are presented in Figures 6, 12, 18 and 24. The sodium concentration test results show that the most rapid reduction of sodium occurred in Column "C" with the slowest reduction occurring in Column "D". Sodium concentration levels reached negligible values after about 1500 DAYS*.

Figure 46, sodium concentration vertical profile curves show the same patterns and trends reported for the other parameters measured. That is, during early TIME* the concentrations are somewhat irregular, followed by a uniform profile at later TIME*. In general, concen-

trations reached minimum values in the upper refuse layers earlier than toward the bottom.

COD

COD concentration curves for the bottom leachate are presented in Figures 7, 13, 19 and 25. Column "A", Figure 7, showed the earliest and most rapid stabilization. This was probably the result of the fact that the column sections were fed fresh distilled water. The results for columns "B", "C", and "D" are similar, showing no advantage to using nutrients to reduce COD concentration levels.

Figure 47 shows COD concentration vertical profile curves. Again the pattern is similar to those developed for the other parameters with highly irregular patterns during early time and similar overlapping profile near the end of the study period.

Leachate Contaminant Cumulative Curves

Figures 32 through 36 present cumulative quantities of contaminant removed plotted against time from the start of the original laboratory lysimeter study. Shown on each curve is the time of initiation of the column tests reported herein.

Of particular significance is the fact that even though at the end of the laboratory lysimeter study the leachate contaminant concentrations were low, a significant leachable quantity of each contaminant (except zinc) remained in the refuse.

The quantity which remained in the refuse varied from less than 5 percent for zinc to approximately 33 percent for chloride.

The curves in Figures 37 through 41 show plots of contaminant removed in grams per square foot versus leachate in liters per square foot. Marked on the curve are two points of significance. The first point is the unit quantity of leachate at which the lysimeter landfill study refuse reached field capacity. The second point is the unit leachate quantity at which the study being discussed herein was initiated. It must be noted that in interpreting these curves, there was a break in experimental continuity as the laboratory lysimeter was dismantled and the column study program initiated.

All plots show that the relationship between quantity of contaminant removed and leachate quantity follows a virtually uniform slope until complete removal is approached. This behavior is seen in the leachate iron curve, Figure 37, the chloride curve, Figure 39, the sodium curve, Figure 40, and the COD curve, Figure 41. The results clearly demonstrate that the use of the semi-log plot of unit contaminant removal against unit leachate quantity is a valuable tool for predicting contaminant removal behavior patterns.

Comparison of D6 Leachate and D7 Leachate

Plots of leachate contaminant concentrations for leachate from the bottom of section 6, Column D and section 7, Column D, are presented in Figures 26 through 31 and 20 through 25 respectively. Complete leachate data for all the columns and all sections can be found in the appendix.

The pH values for the D7 leachate appears to have been slightly more acid and more erratic in concentrations. However, the plots for all other contaminant concentrations appear very similar with no major differences apparent. However, a review of the general vertical profile curves for the various contaminants, Figures 42 through 47, shows that overall pollutant concentrations increase with refuse depth. This trend suggests that the upper refuse layers stabilize earlier than the deeper layers, assuming simultaneous placement.

SECTION 4

FIELD FACILITY EXPERIMENTAL STUDY

The field facility was described in complete detail in the Final Report. Of particular interest in this report is the arrangement of the deep and shallow ground water observation and sampling wells. The locations of the deep wells reported herein, wells 3, 12 and 13, are shown in Figure 48. Figure 48 is the same as Figure 13 in the Final Report. The locations of the shallow ground water wells are shown in Figure 49. Figure 49 is the same as Figure 18 in the Final Report.

In this study, only ground water quality in selected wells was monitored (Figures 50 through 101); temperature and gas monitoring was discontinued. This reduced activity was the result of limited funds, and the decision to monitor only ground water quality was due to the fact that temperature and gas behavior patterns appeared to be reasonably well defined by the initial study.

Background ground water quality data was collected at the site prior to installation of the test cell in the spring of 1968. Complete ground water background data can be found in the Final Report. Overall background ground water quality was good with only low concentrations of the various contaminants present.

The deep ground water wells 12 and 13 are directly under the refuse center, while well number 3 is outside the refuse down ground water gradient.

The shallow ground water wells are all down gradient from the surface.

Deep Well Study

The ground water data from wells number 12 and 13 beneath the refuse and well number 3 down ground water gradient from the refuse are presented as typical of the deep ground water wells. The general direction of ground water flow is from wells number 12 and 13 toward well number 3.

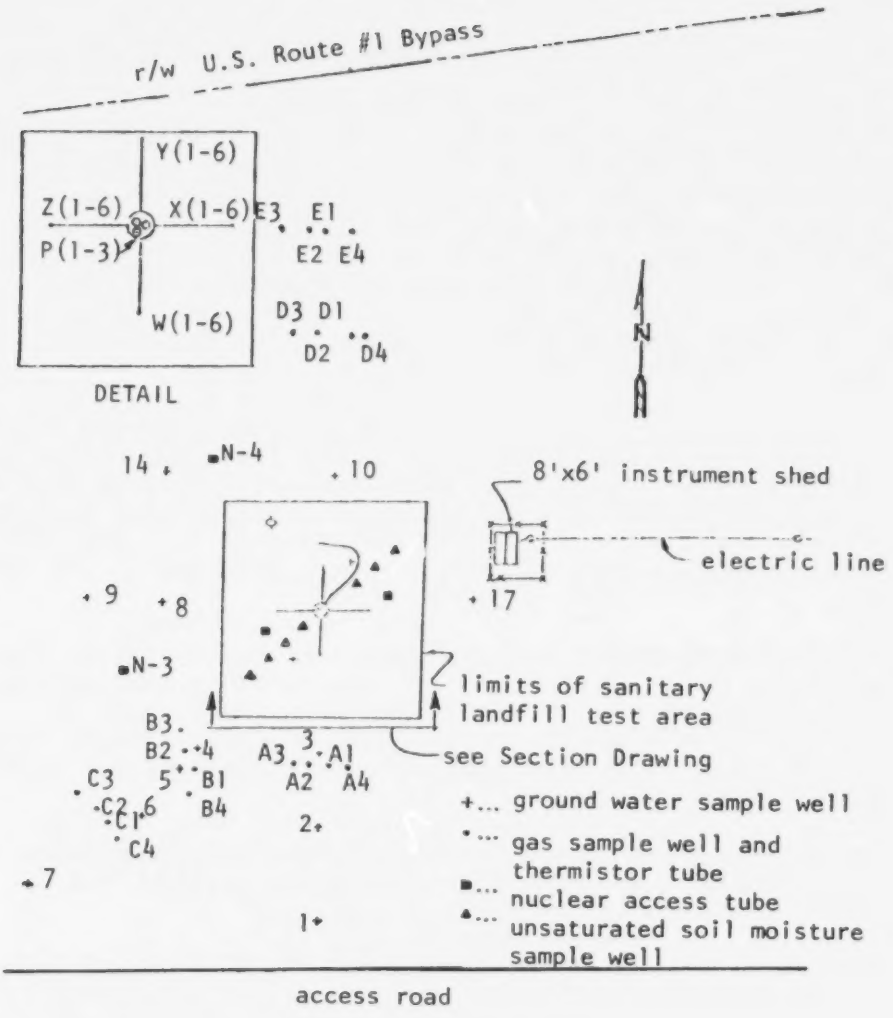


FIGURE 48. KENNETT SQUARE PLOT PLAN

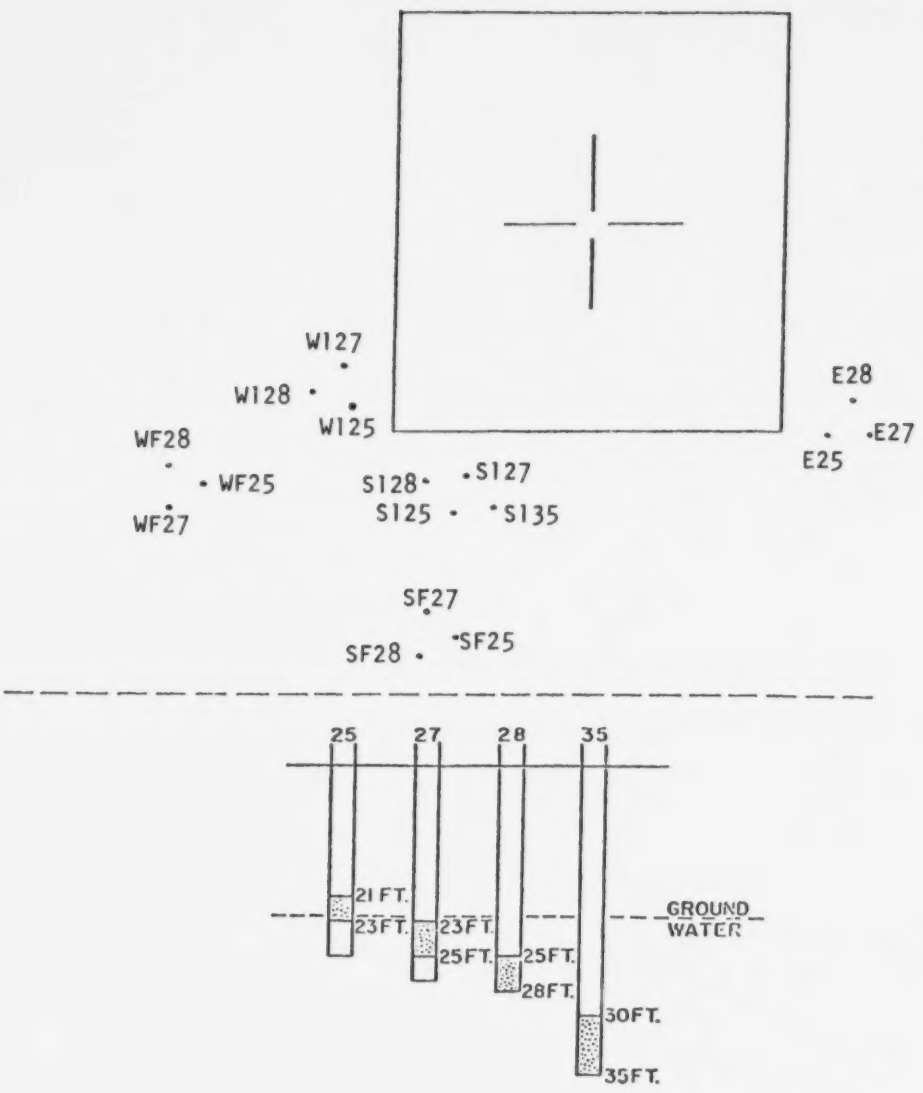


FIGURE 49. SHALLOW WELL CLUSTER LOCATIONS

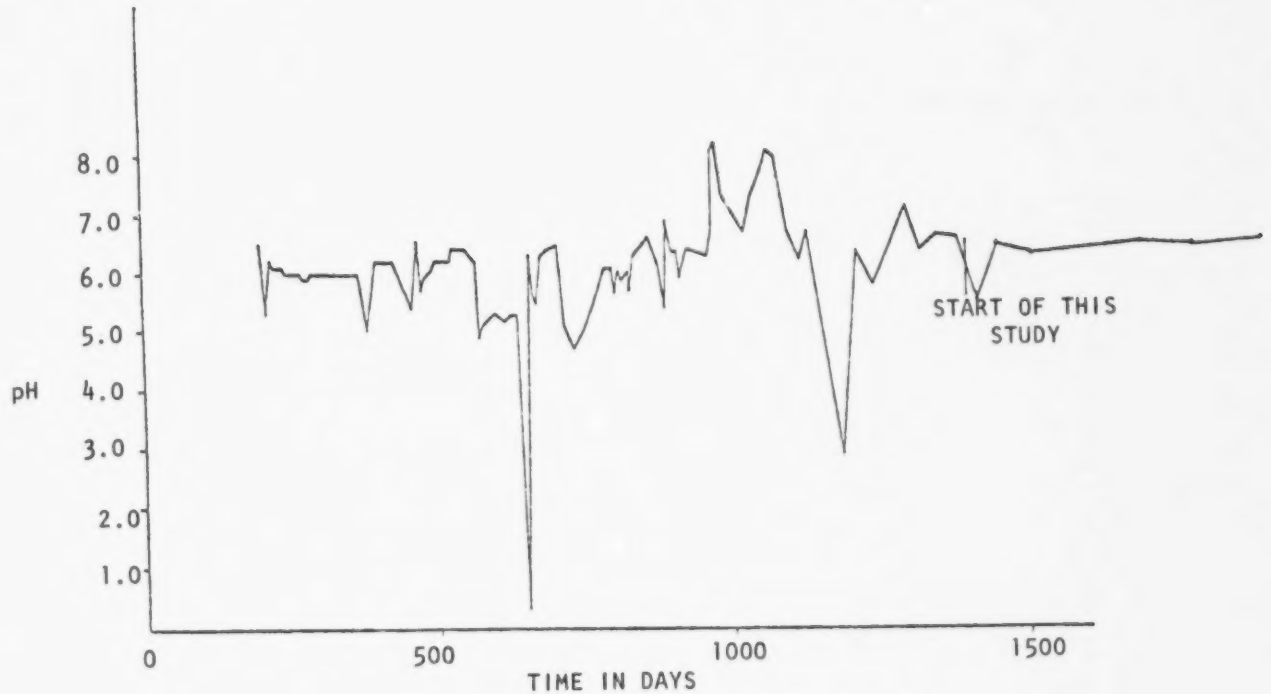


FIGURE 50. pH - TEST WELL NO. 12

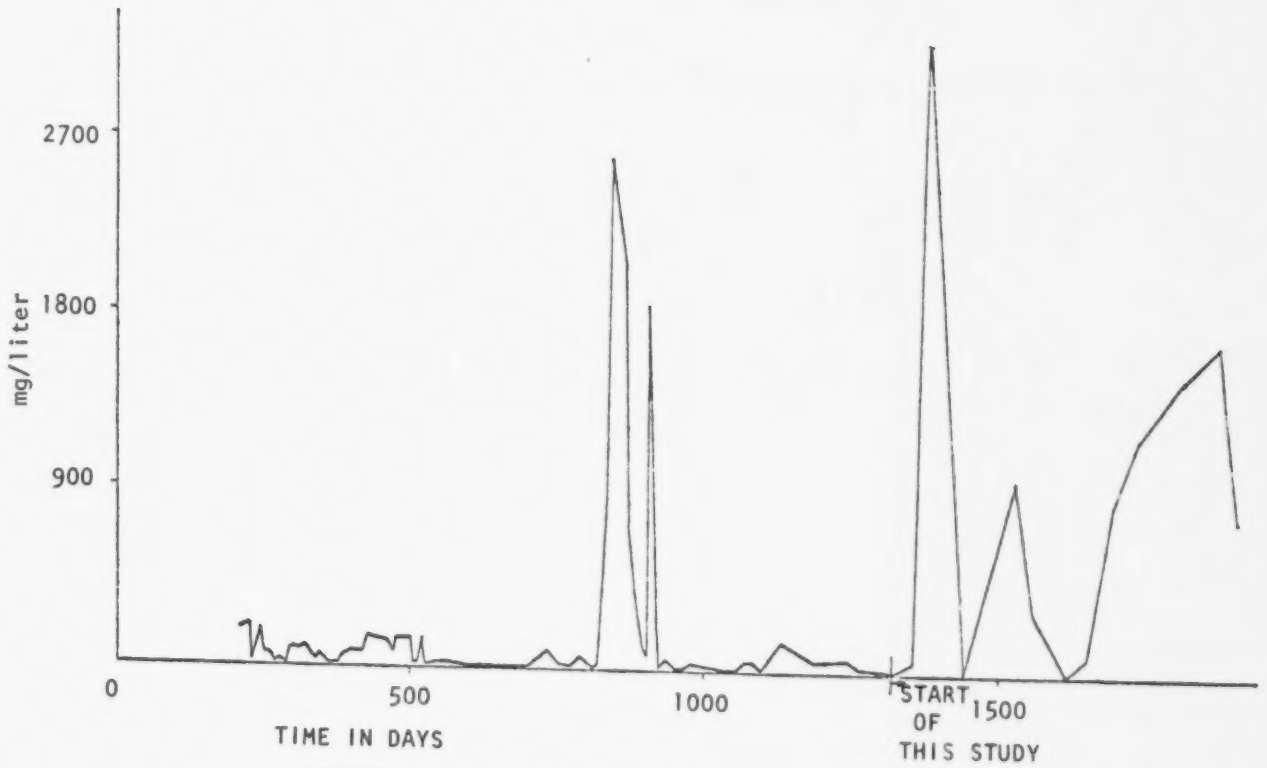


FIGURE 51. CHEMICAL OXYGEN DEMAND - TEST WELL NO. 12

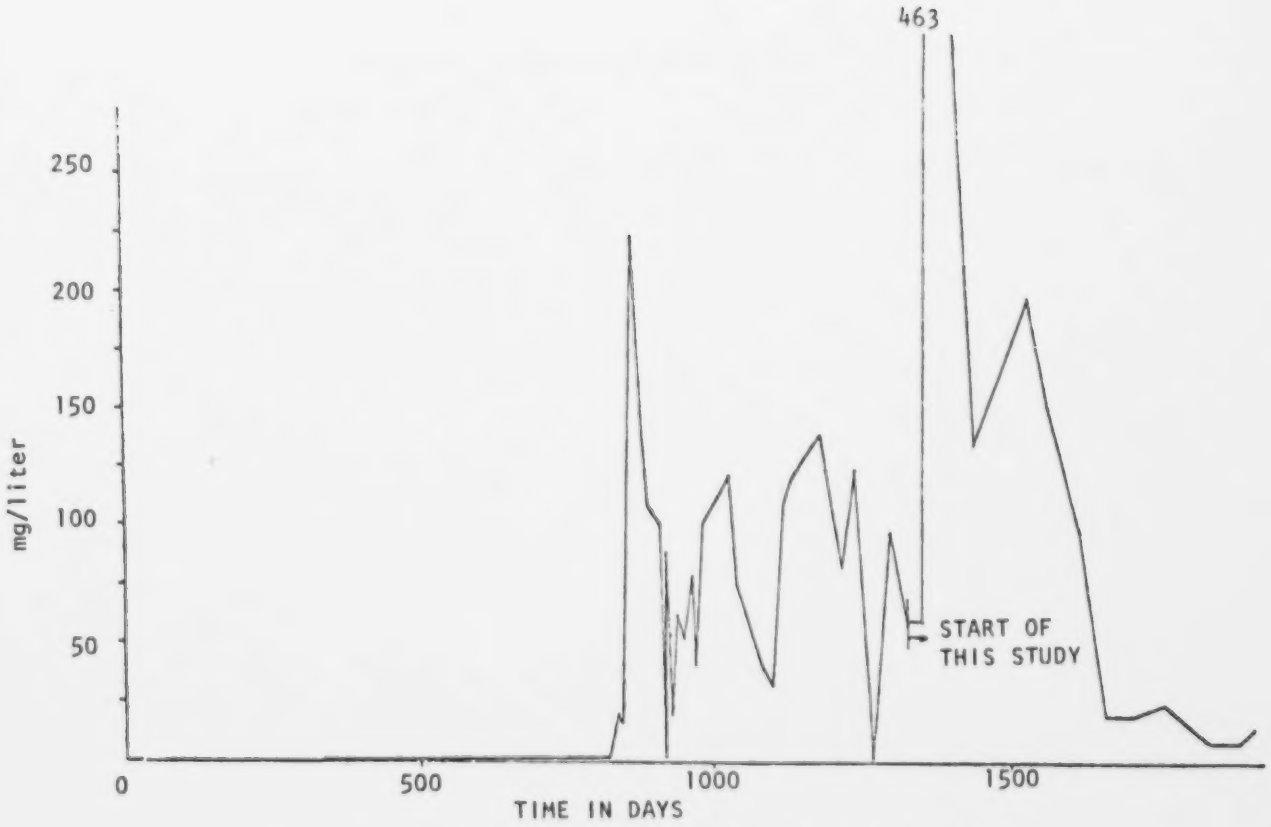


FIGURE 52. IRON - TEST WELL NO. 12

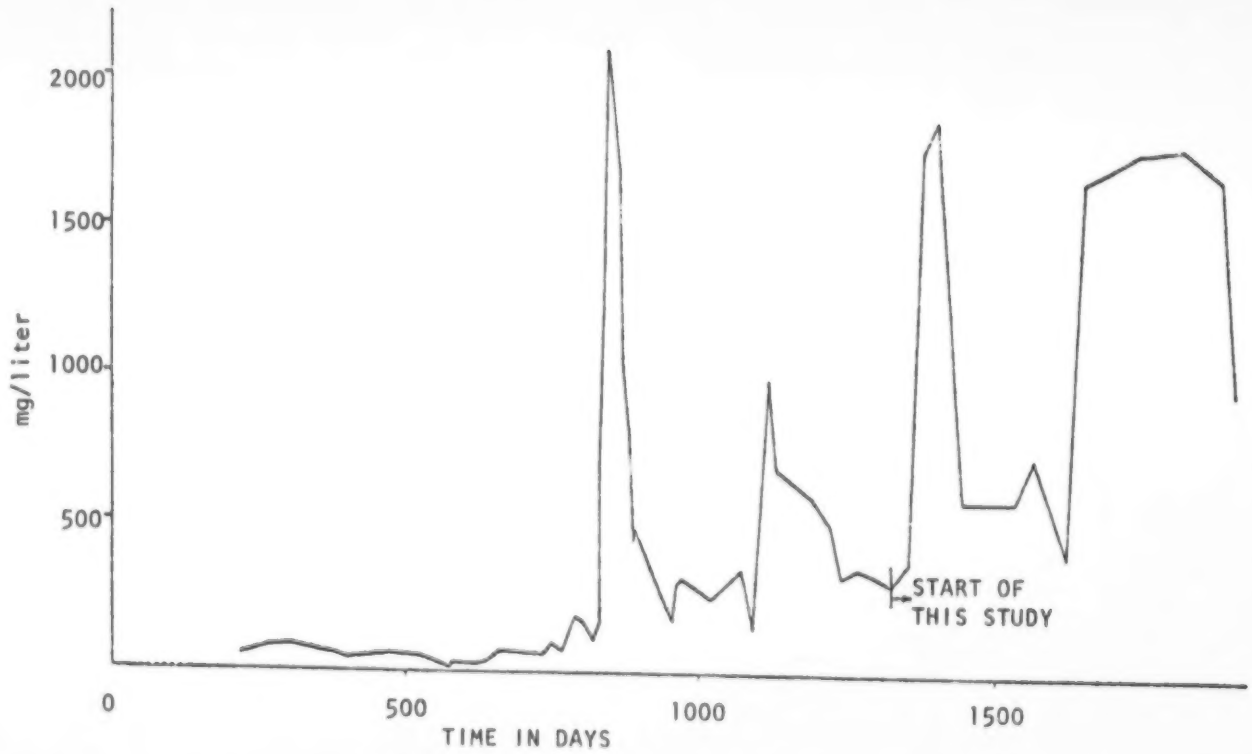


FIGURE 53. TOTAL DISSOLVED SOLIDS - TEST WELL NO. 12

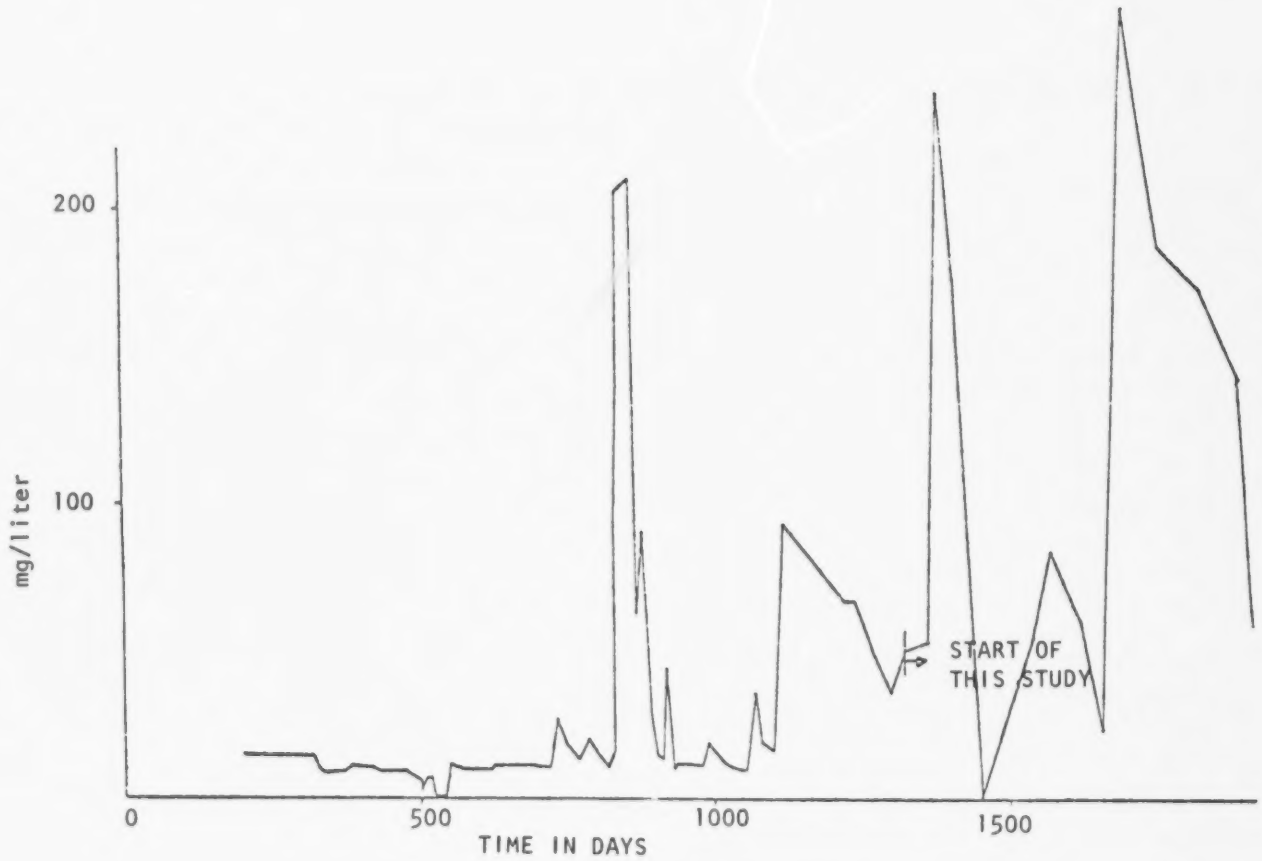


FIGURE 54. CHLORIDE - TEST WELL NO. 12

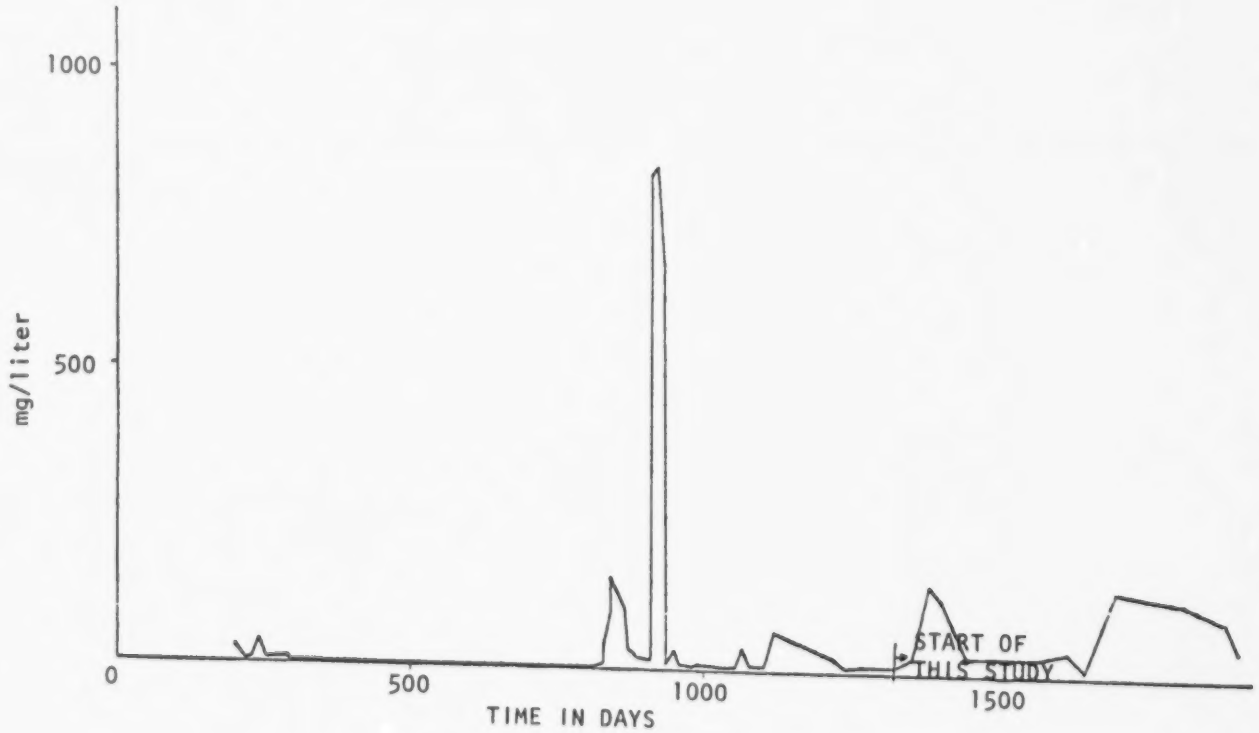


FIGURE 55. SODIUM - TEST WELL NO. 12

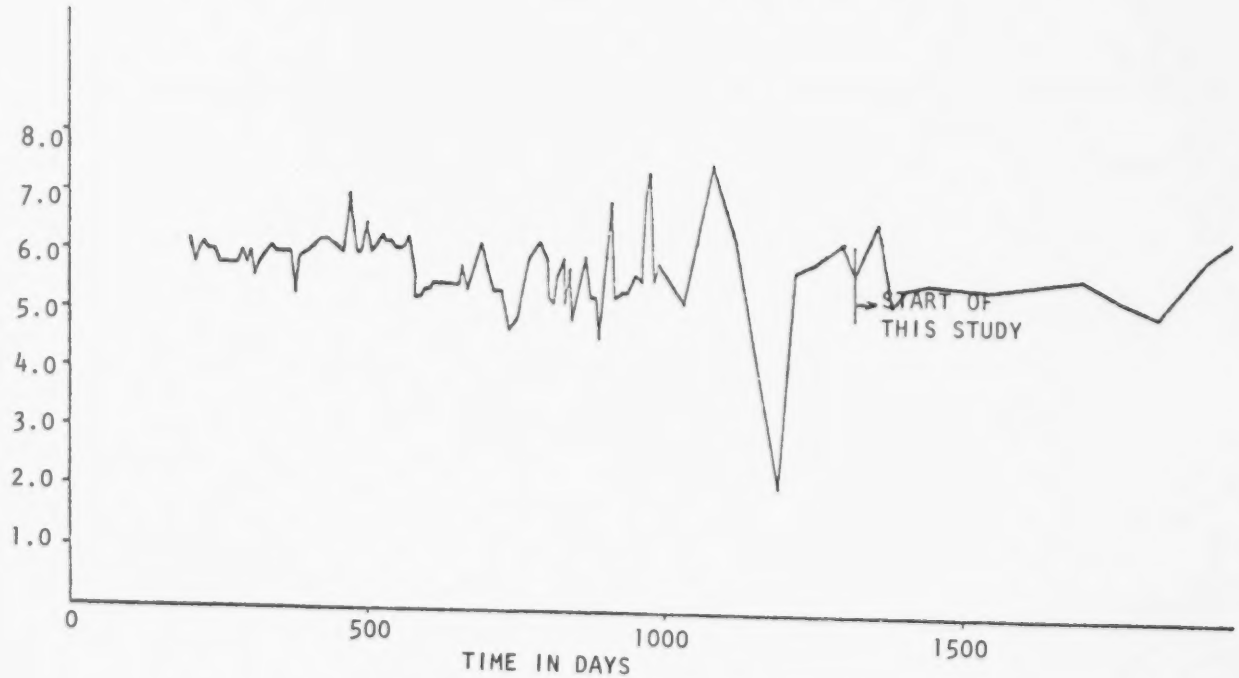


FIGURE 56. pH - TEST WELL NO. 13

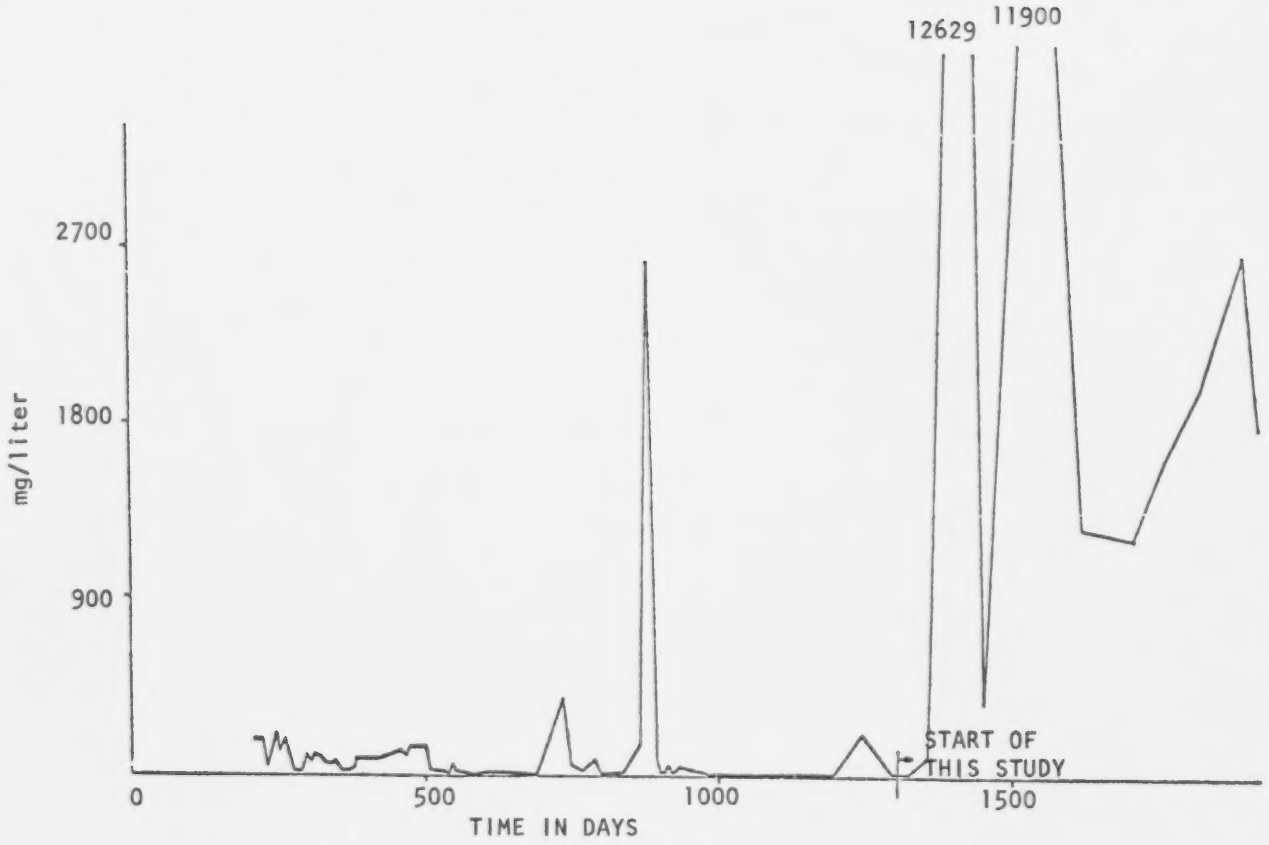


FIGURE 57. CHEMICAL OXYGEN DEMAND - TEST WELL NO. 13

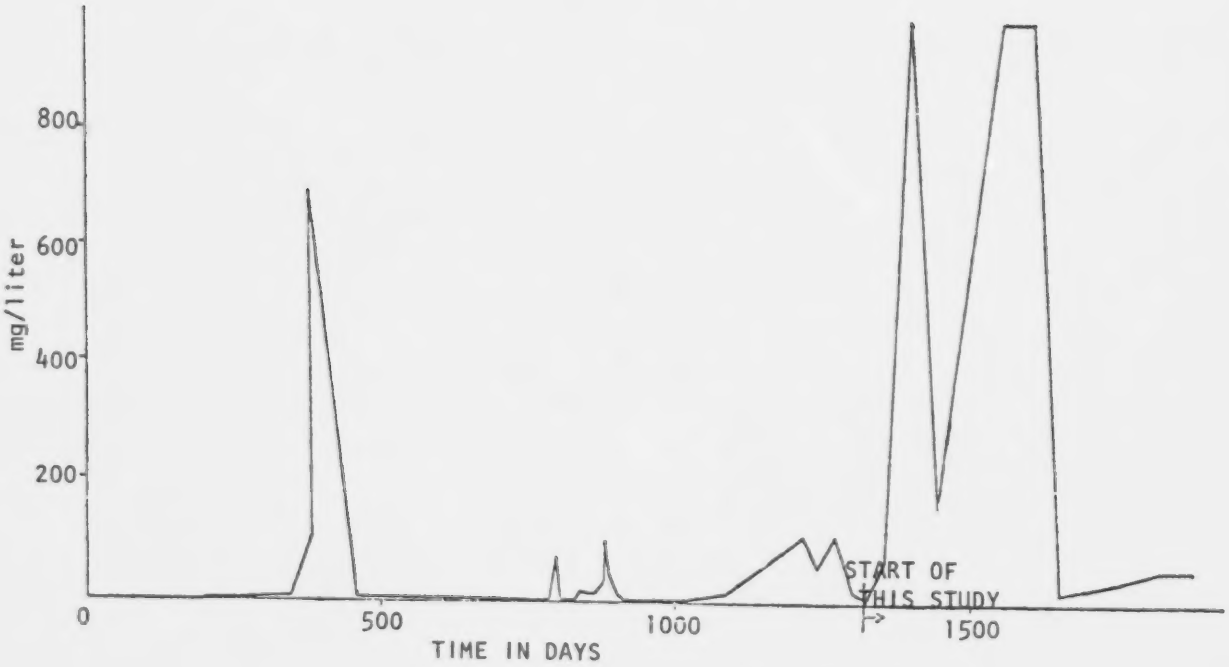


FIGURE 58. IRON - TEST WELL NO. 13

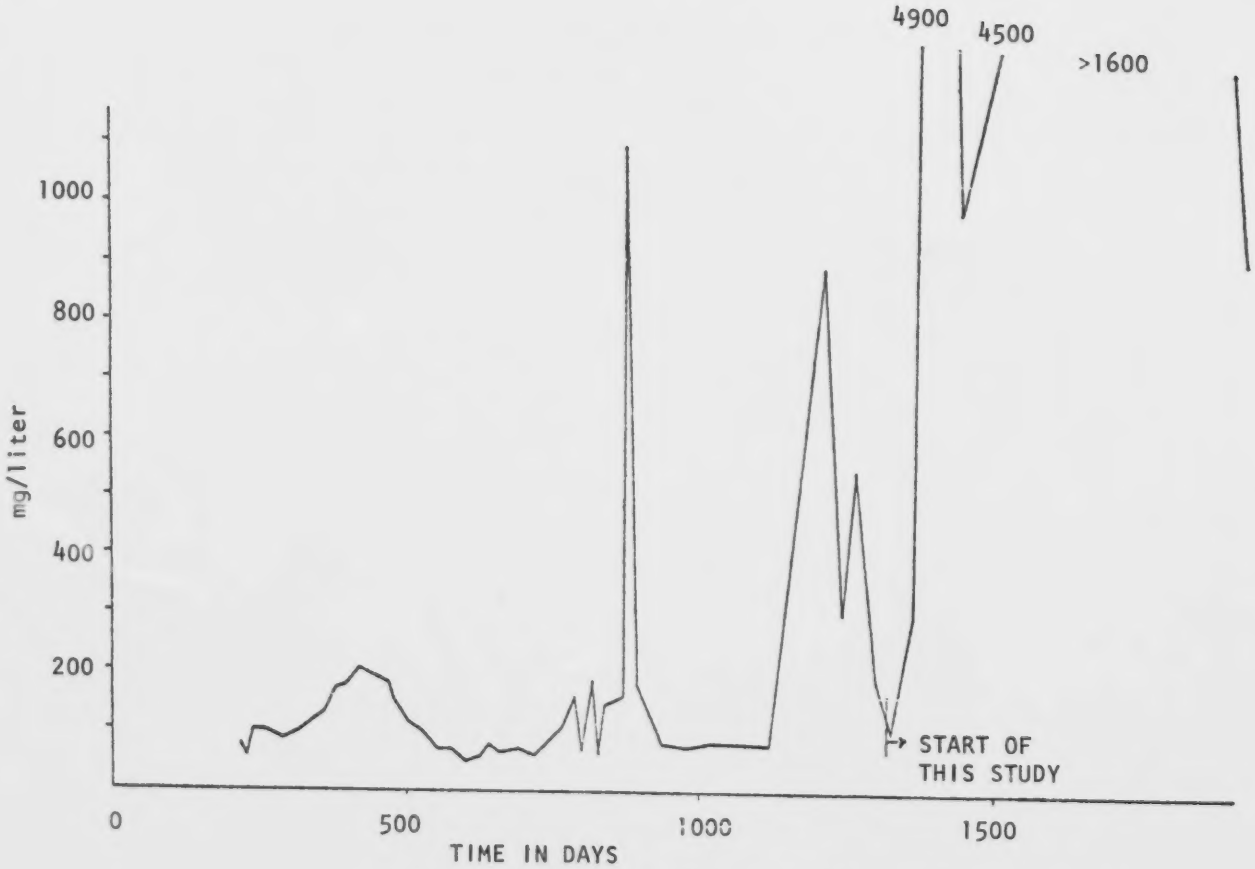


FIGURE 59. TOTAL DISSOLVED SOLIDS - TEST WELL NO. 13

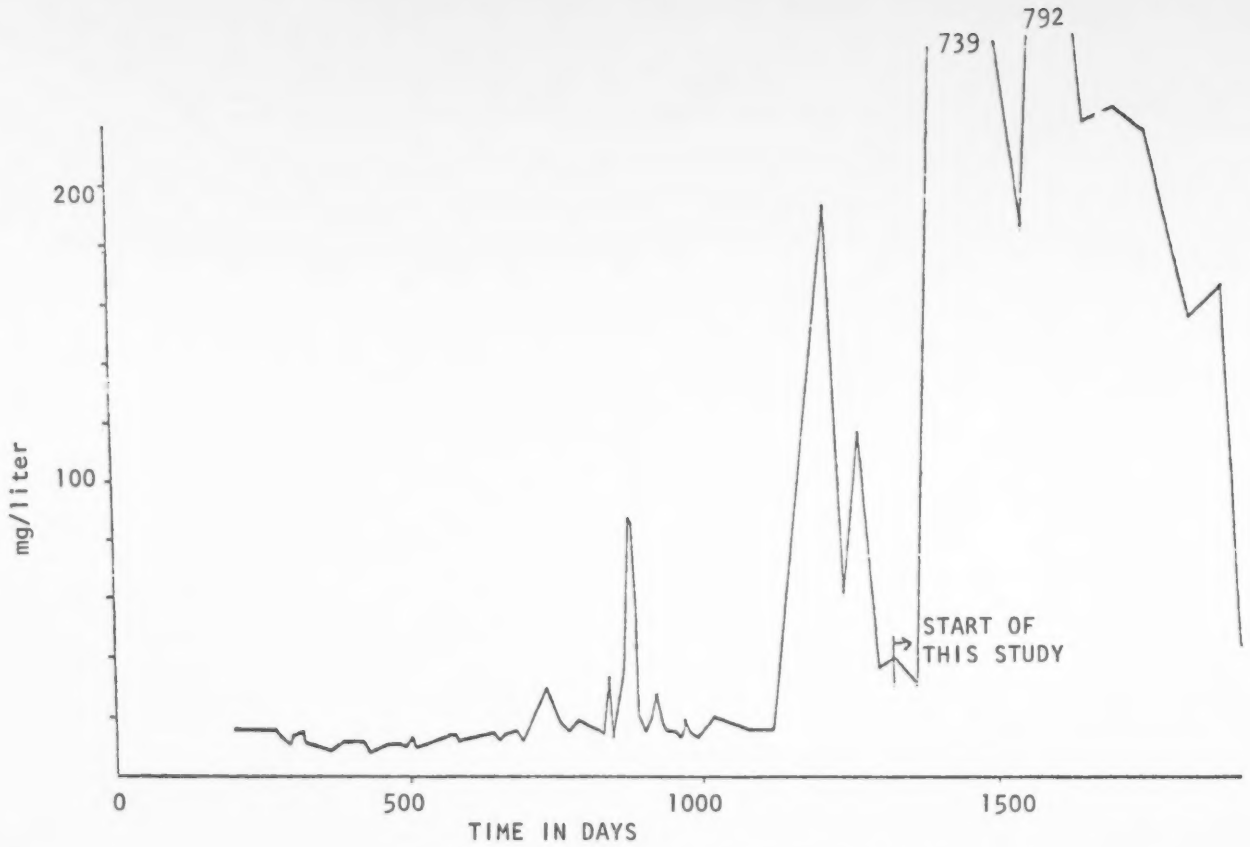


FIGURE 60. CHLORIDE - TEST WELL NO. 13

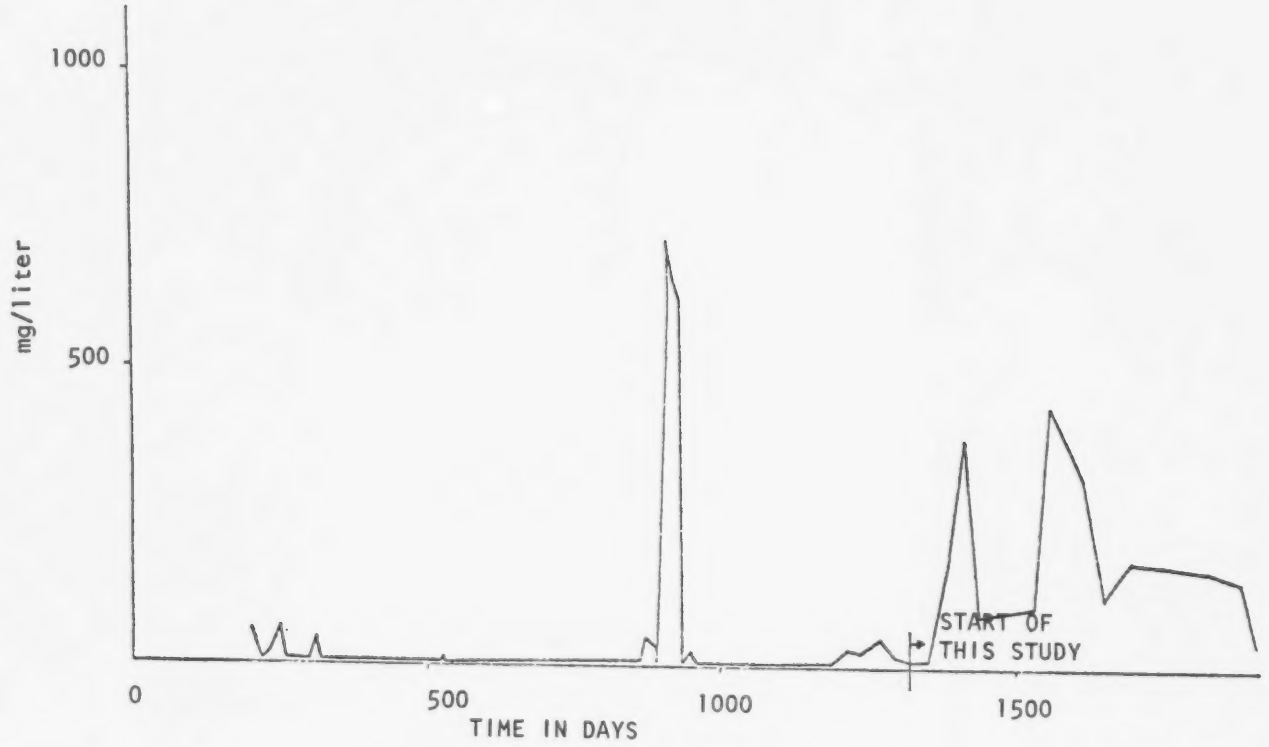
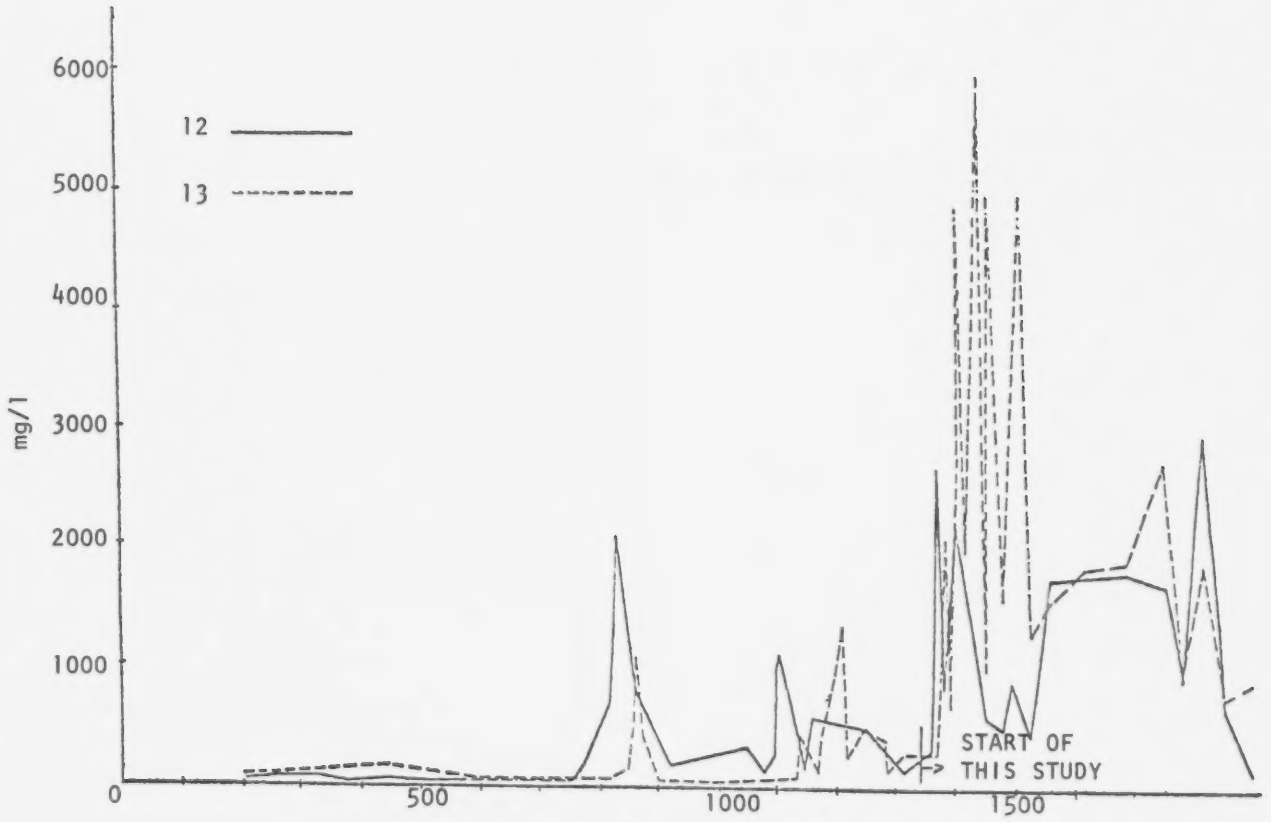


FIGURE 61. SODIUM - TEST WELL NO. 13



TIME IN DAYS FROM DECEMBER 12, 1967

FIGURE 62. TOTAL DISSOLVED SOLIDS - GROUNDWATER

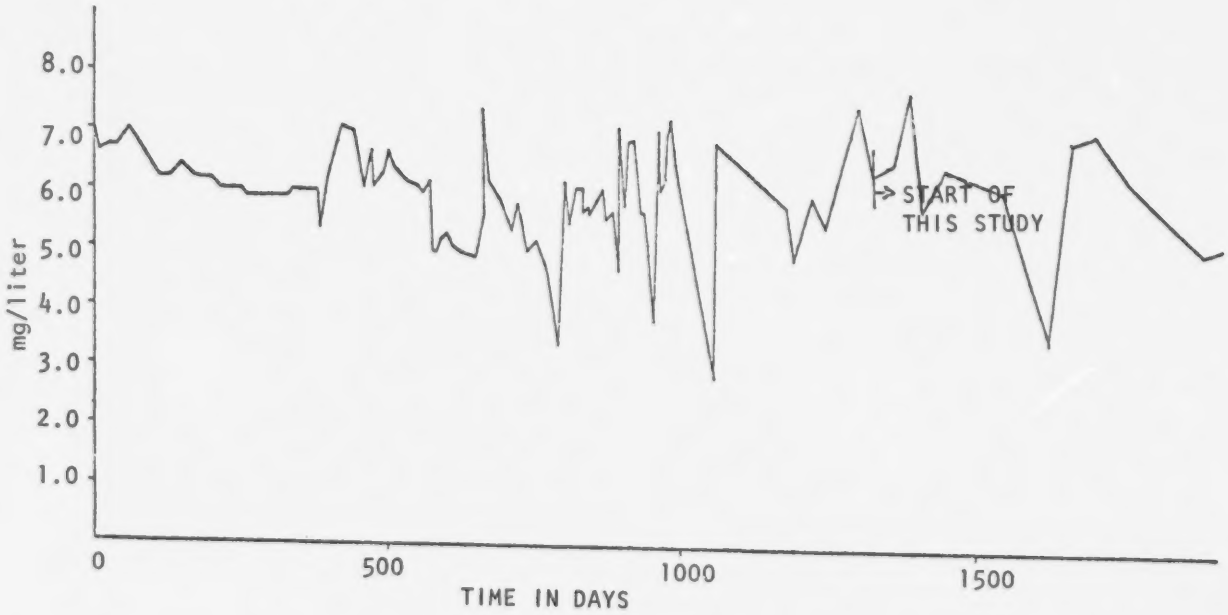


FIGURE 63. pH - TEST WELL NO. 3

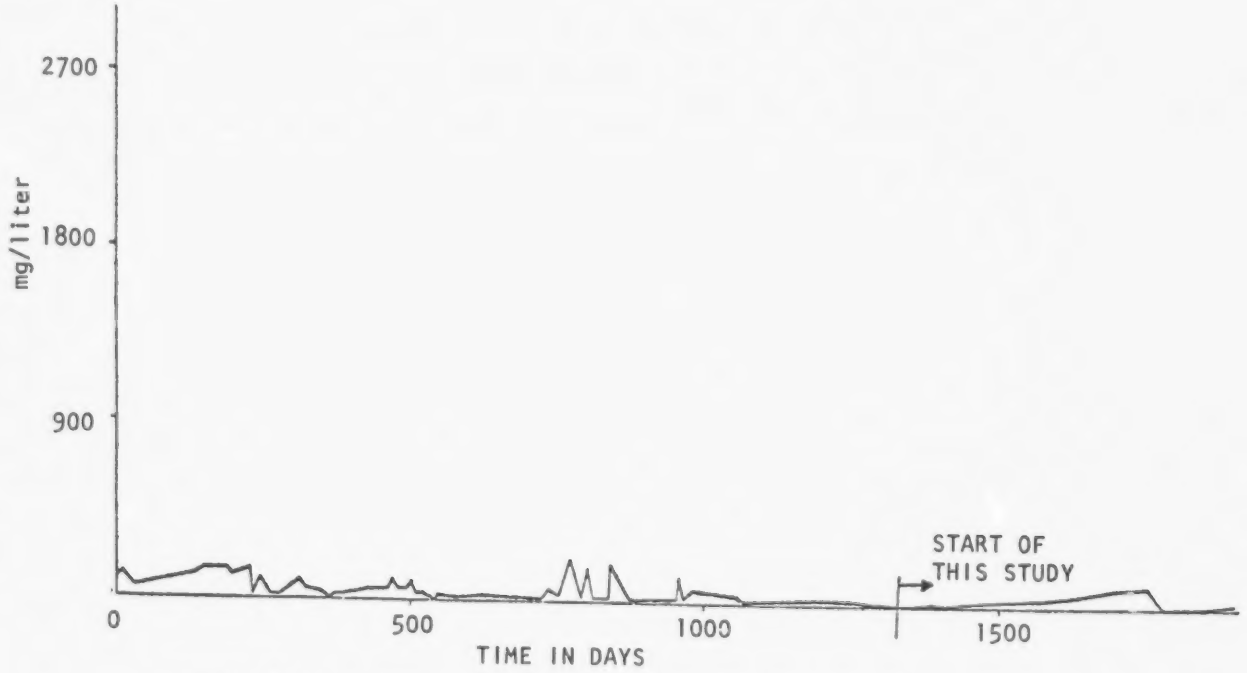


FIGURE 64. CHEMICAL OXYGEN DEMAND - TEST WELL NO. 3

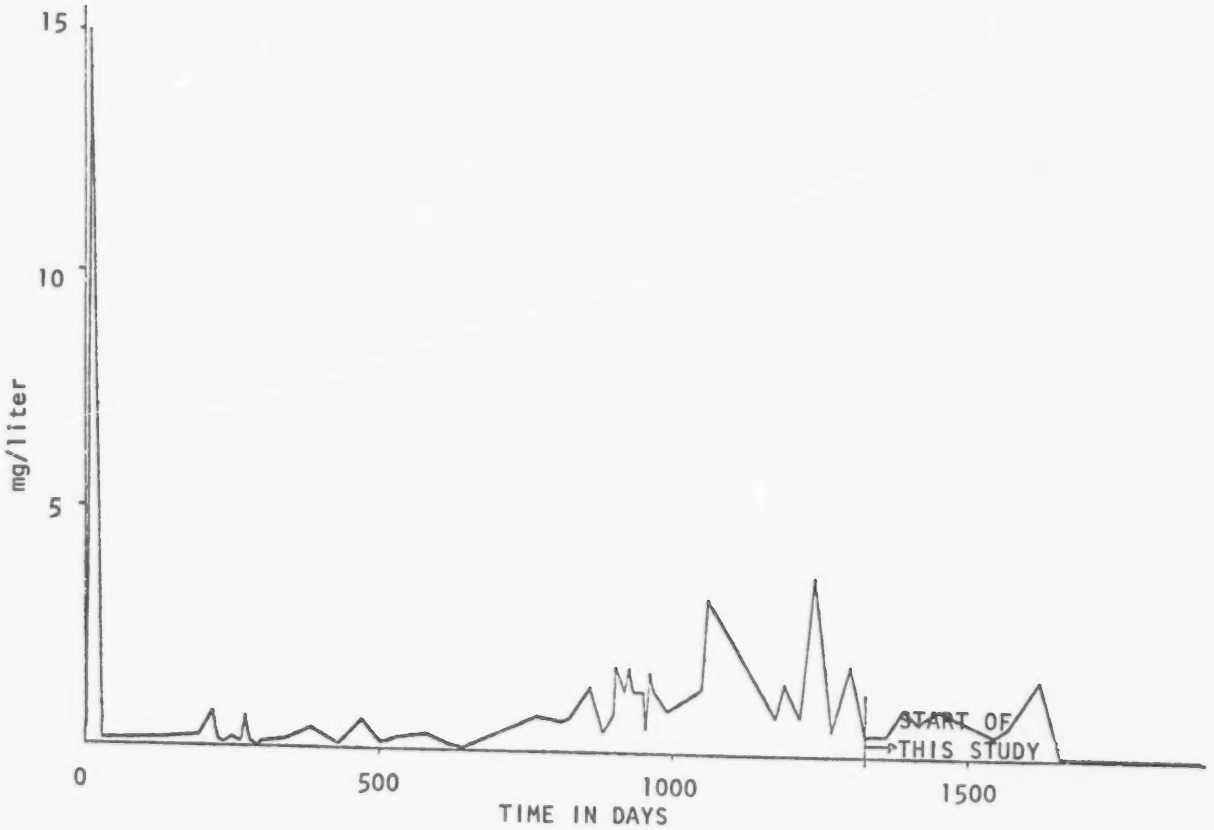


FIGURE 65. IRON CONCENTRATION - TEST WELL NO. 3

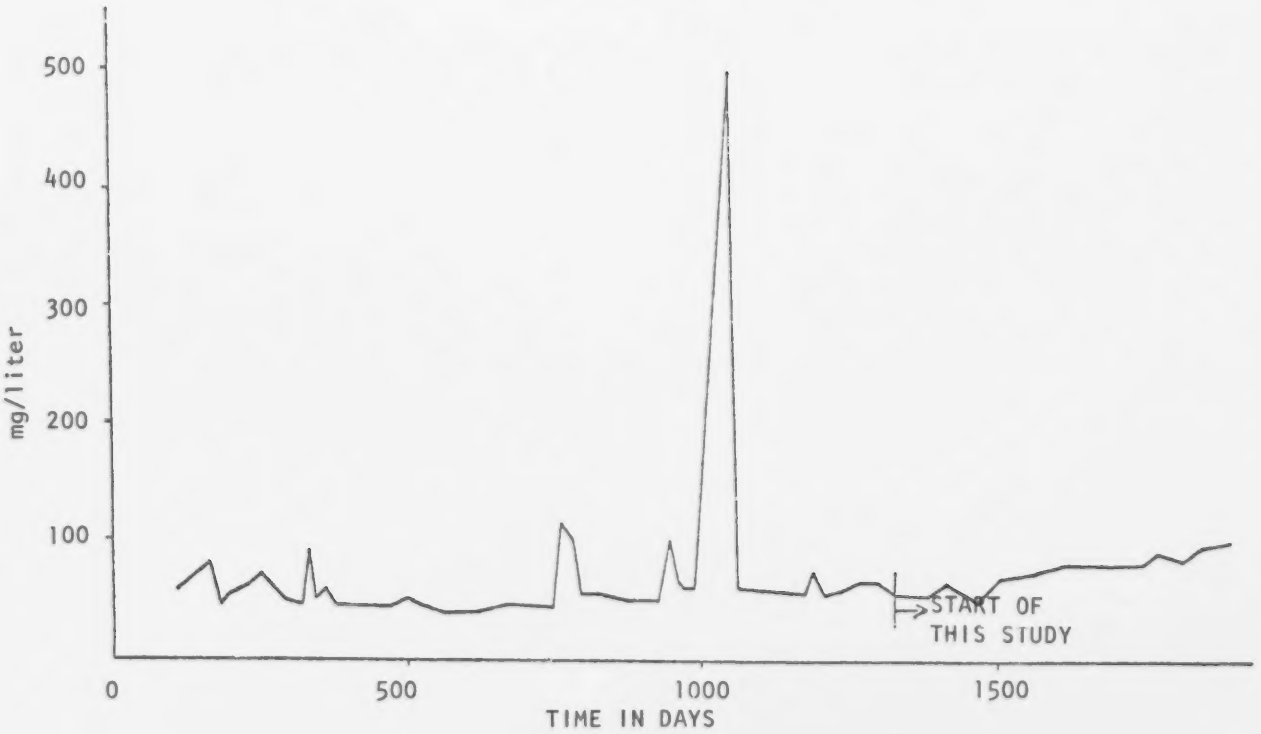


FIGURE 66. TOTAL DISSOLVED SOLIDS - TEST WELL NO. 3

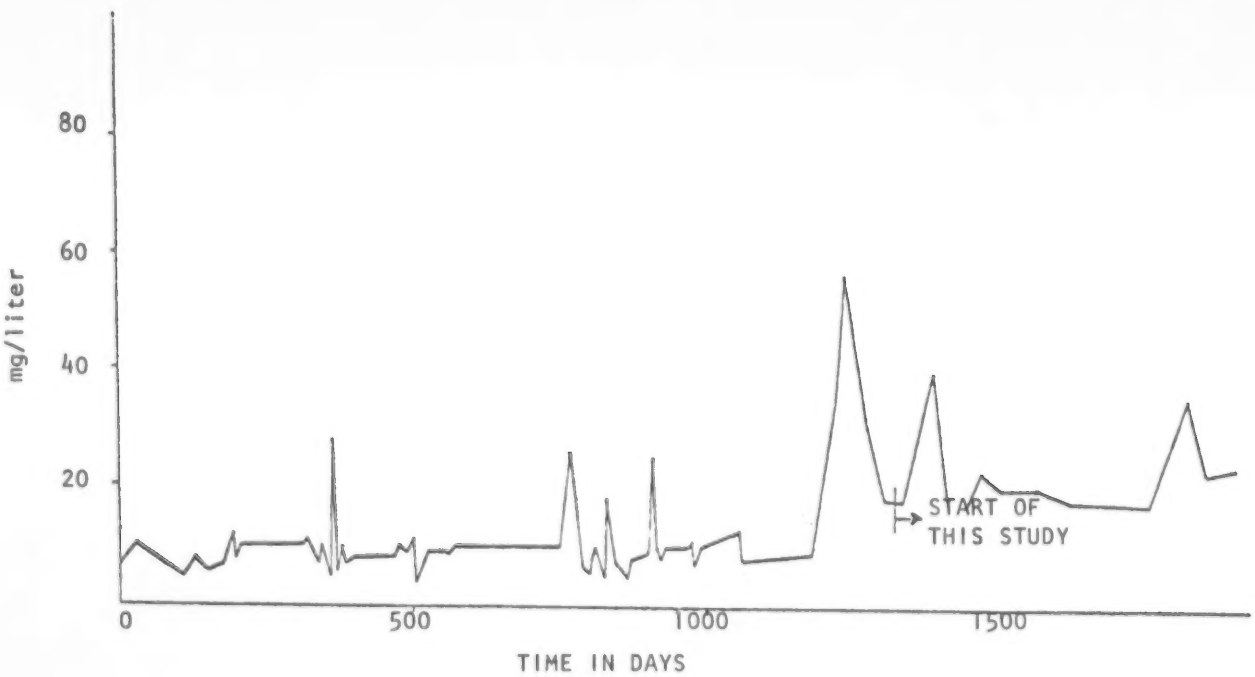


FIGURE 67. CHLORIDE - TEST WELL NO. 3

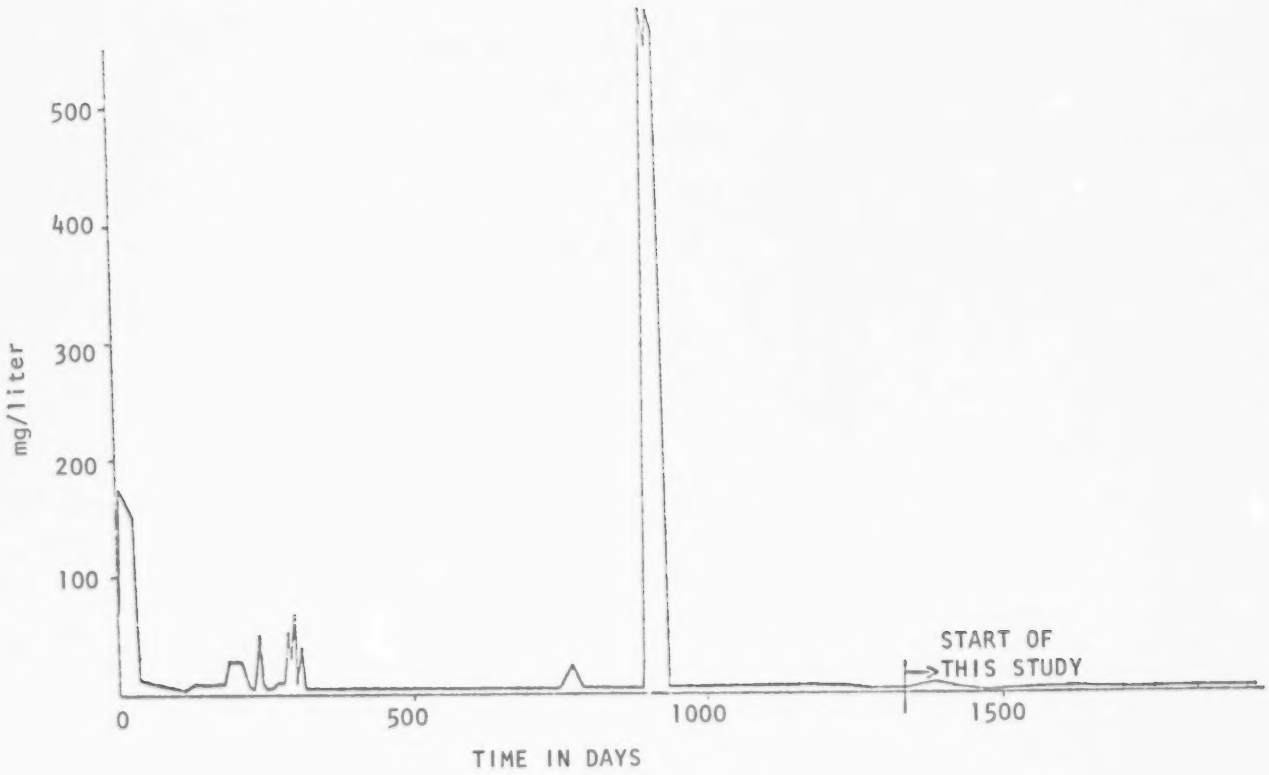


FIGURE 68. SODIUM - TEST WELL NO. 3

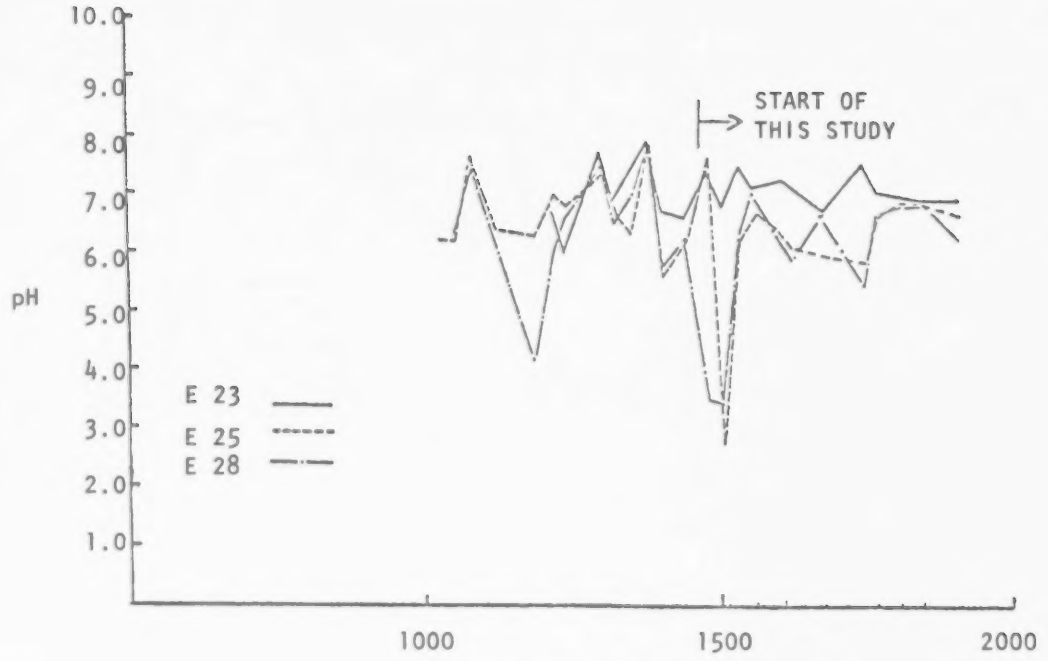


FIGURE 69. FIELD TEST LANDFILL. E WELL SERIES - pH FACTOR

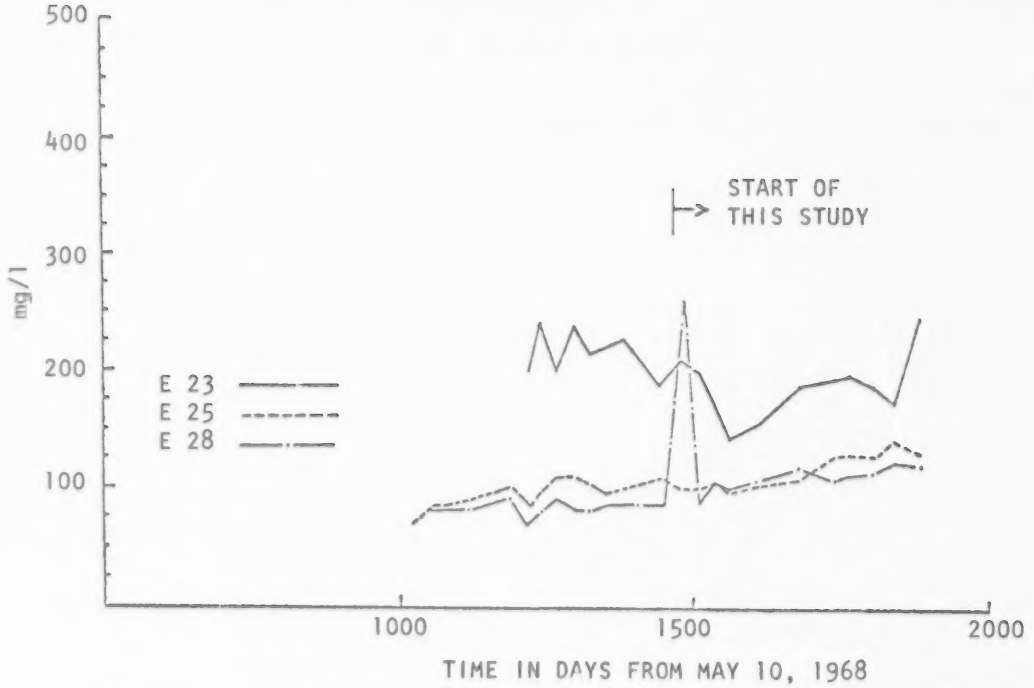


FIGURE 70. FIELD TEST LANDFILL. E WELL SERIES - TDS CONCENTRATION

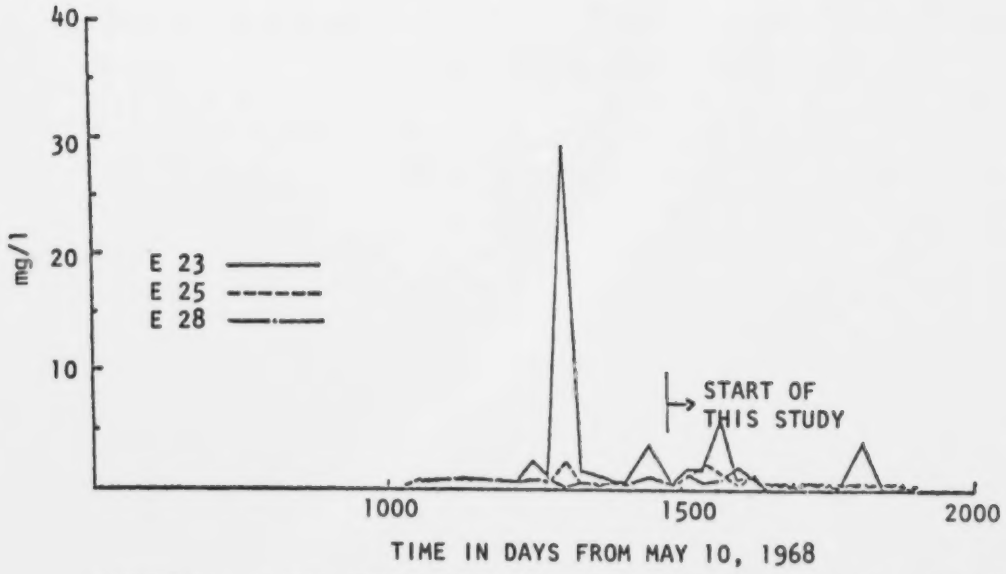


FIGURE 71. FIELD TEST LANDFILL. E WELL SERIES - IRON CONCENTRATION

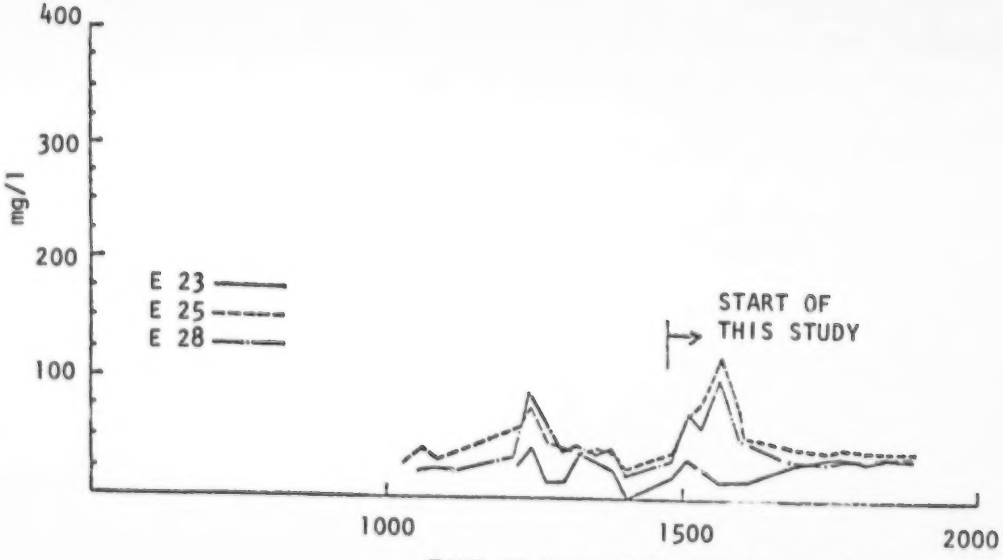


FIGURE 72. FIELD TEST LANDFILL. E WELL SERIES - CHLORIDE CONCENTRATION

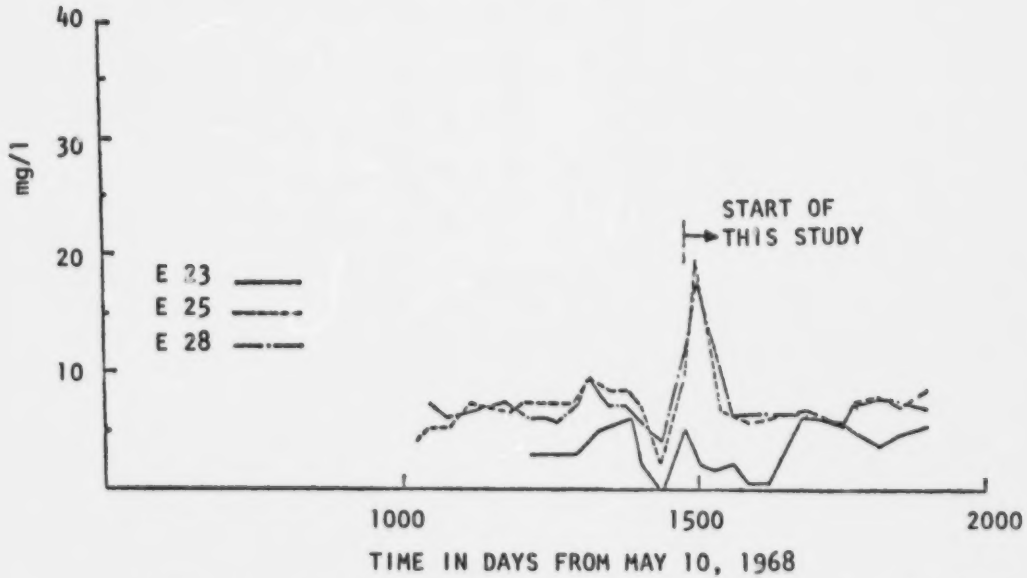


FIGURE 73. FIELD TEST LANDFILL. E WELL SERIES - Na CONCENTRATION

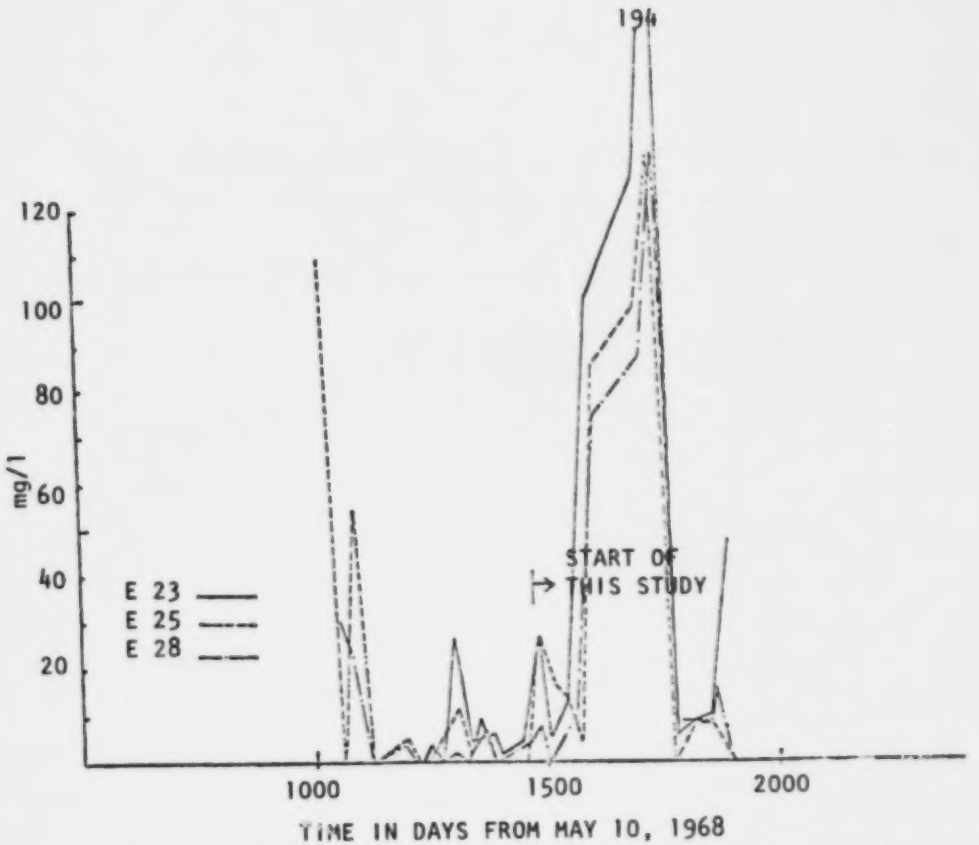


FIGURE 74. FIELD TEST LANDFILL. E WELL SERIES - COD CONCENTRATION

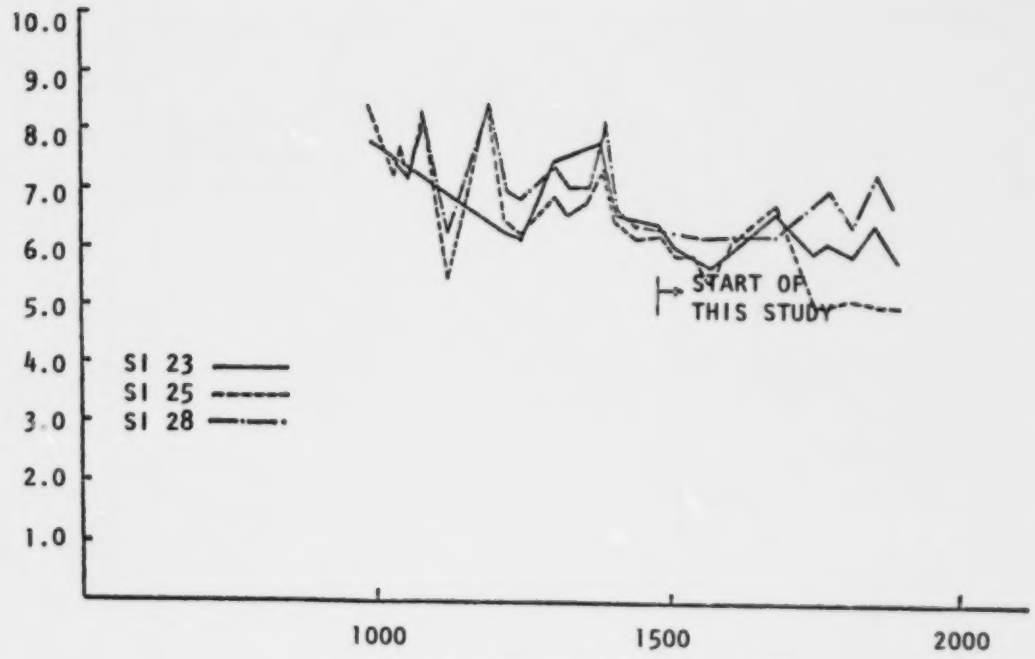


FIGURE 75. FIELD TEST LANDFILL. SI WELL SERIES - pH FACTOR

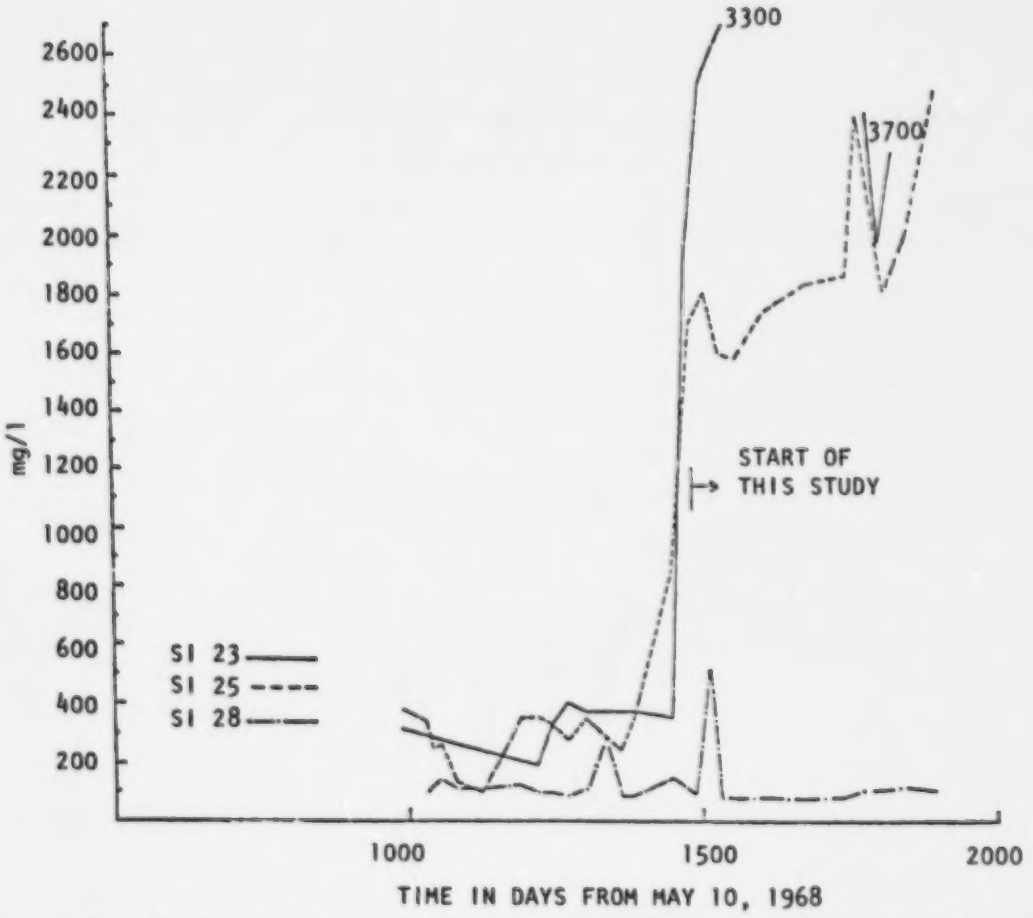


FIGURE 76. FIELD TEST LANDFILL. SI WELL SERIES - TDS CONCENTRATION

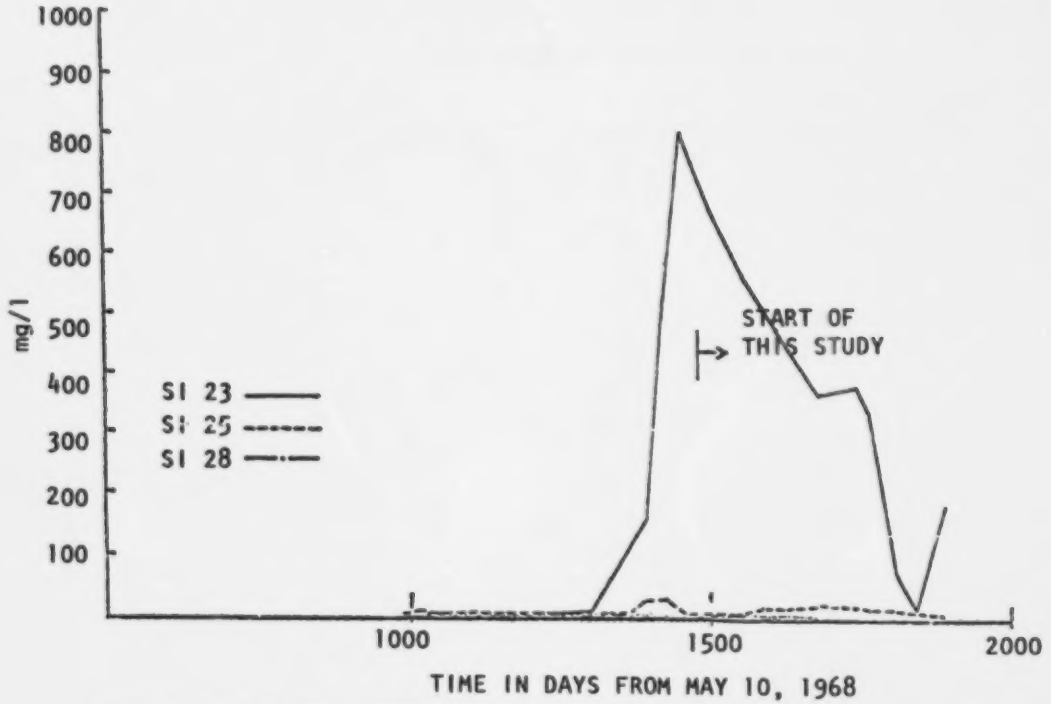


FIGURE 77. FIELD TEST LANDFILL. SI WELL SERIES - IRON CONCENTRATION

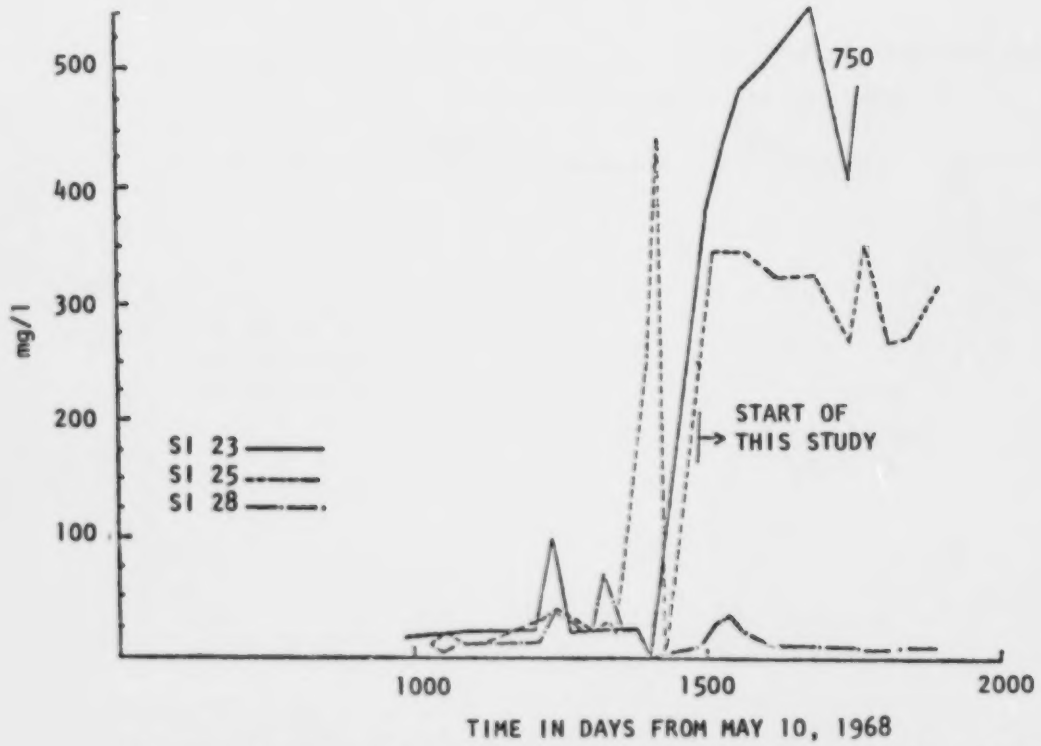


FIGURE 78. FIELD TEST LANDFILL. SI WELL SERIES - CHLORIDE CONCENTRATION

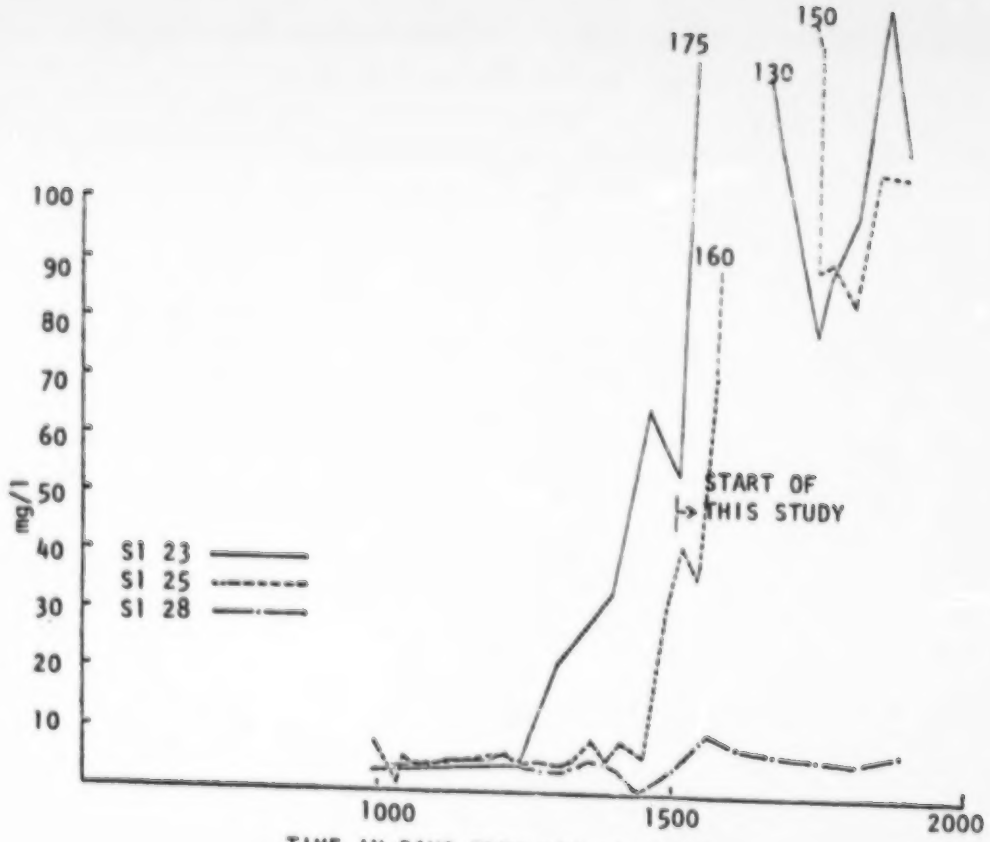


FIGURE 79. FIELD TEST LANDFILL. SI SERIES - Na CONCENTRATION

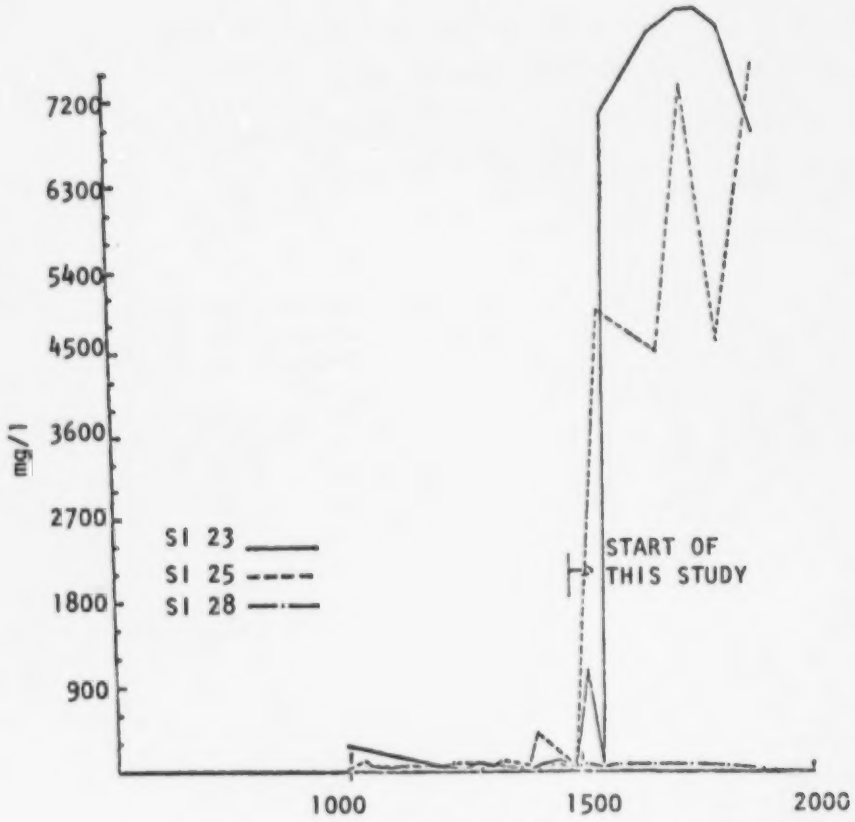


FIGURE 80. FIELD TEST LANDFILL. SI WELL SERIES - COD CONCENTRATION

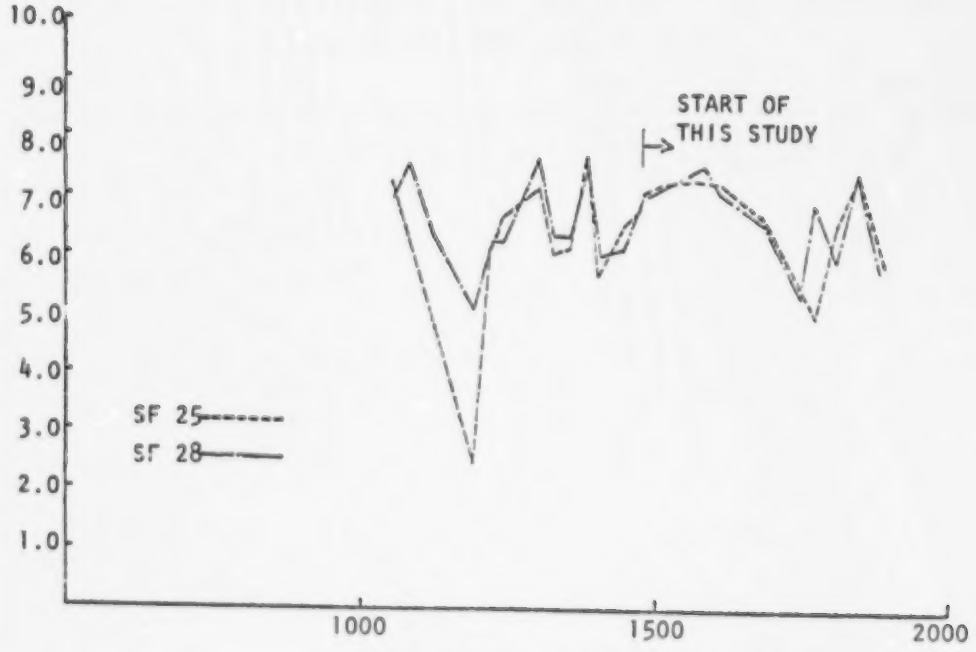


FIGURE 81. FIELD TEST LANDFILL. SF WELL SERIES - pH FACTOR

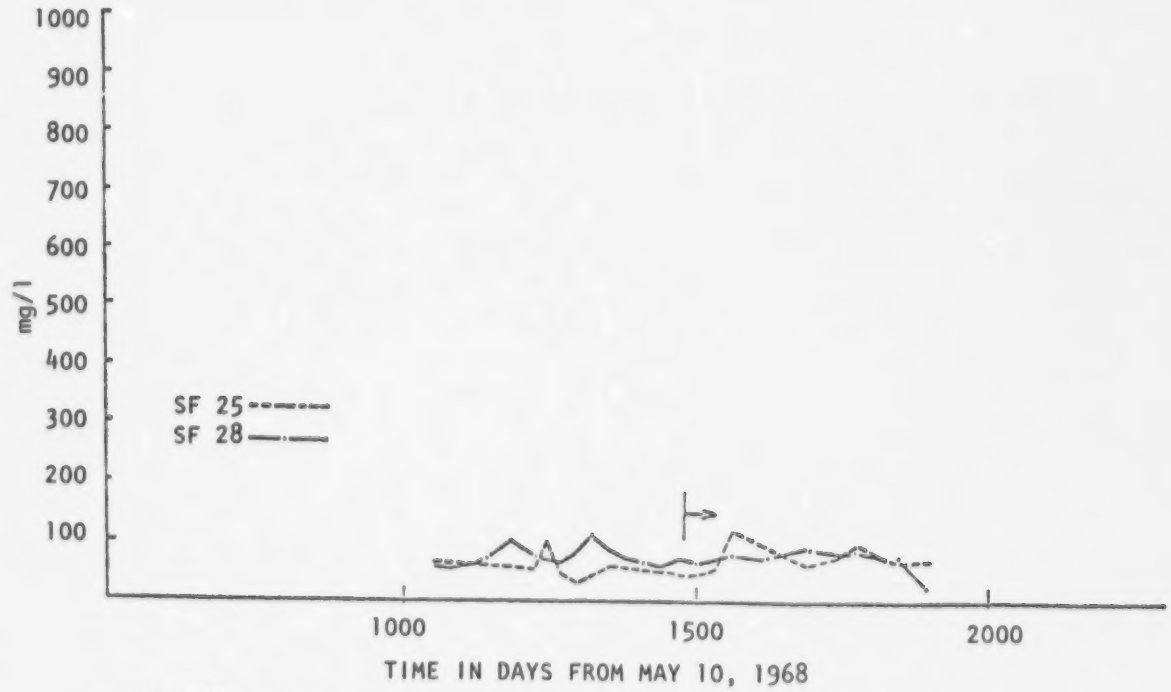


FIGURE 82. FIELD TEST LANDFILL. SF WELL SERIES - TDS CONCENTRATION

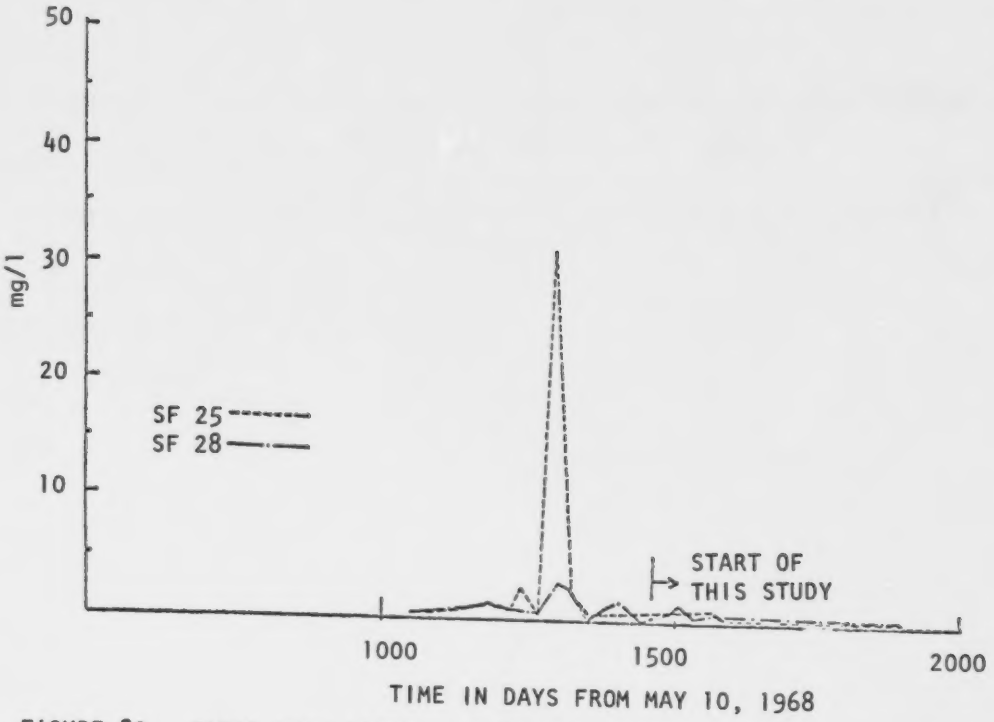


FIGURE 83. FIELD TEST LANDFILL. SF WELL SERIES - IRON CONCENTRATION

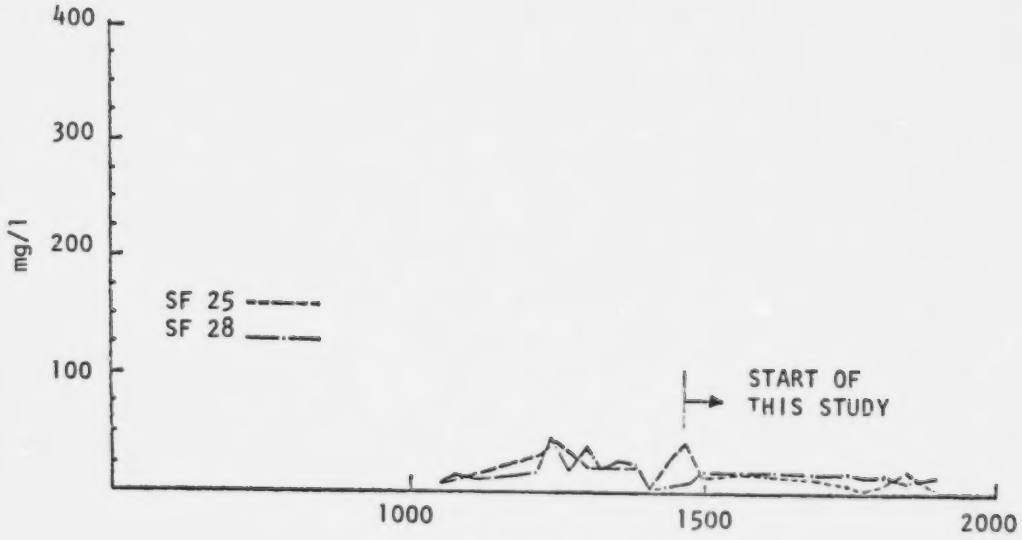


FIGURE 84. FIELD TEST LANDFILL SF WELL SERIES - CHLORIDE CONCENTRATION

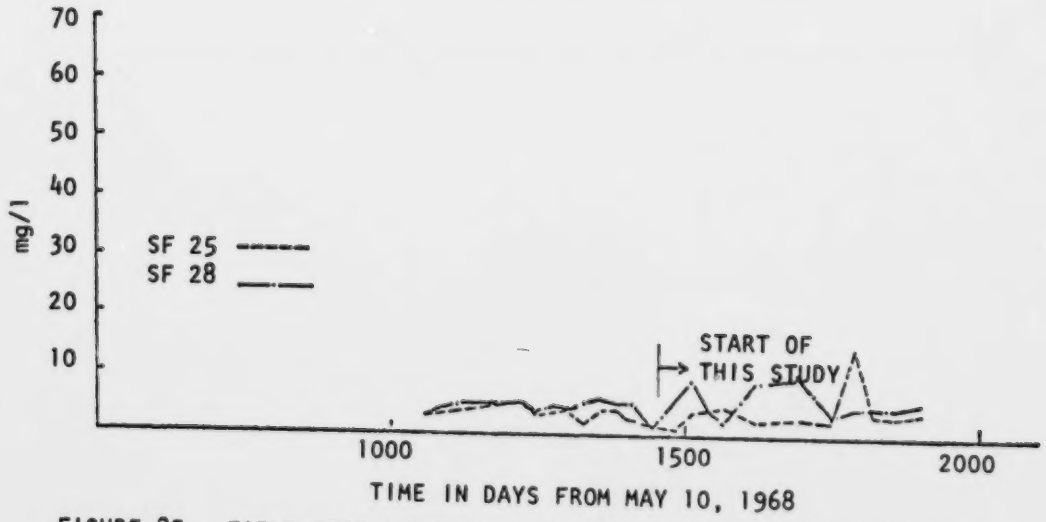


FIGURE 85. FIELD TEST LANDFILL. SF WELL SERIES - Na CONCENTRATION

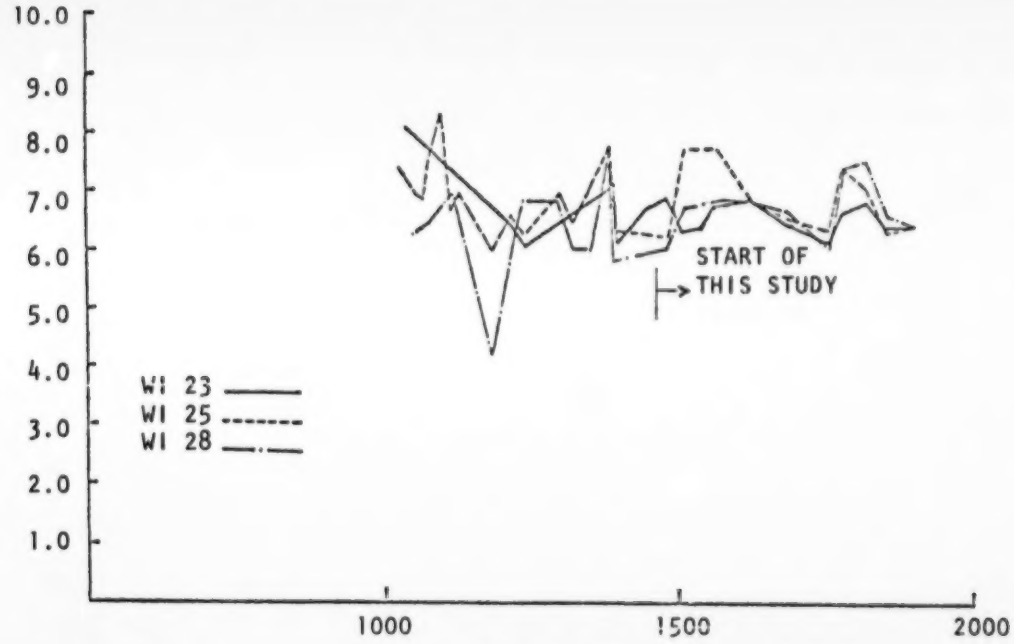


FIGURE 86. FIELD TEST LANDFILL. WI WELL SERIES - pH FACTOR

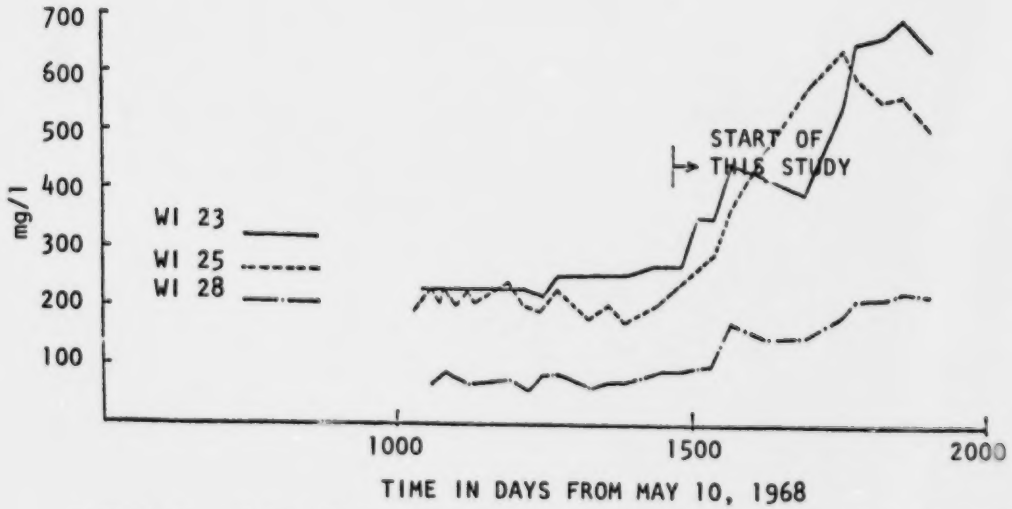


FIGURE 87. FIELD TEST LANDFILL. WI WELL SERIES - TDS CONCENTRATION

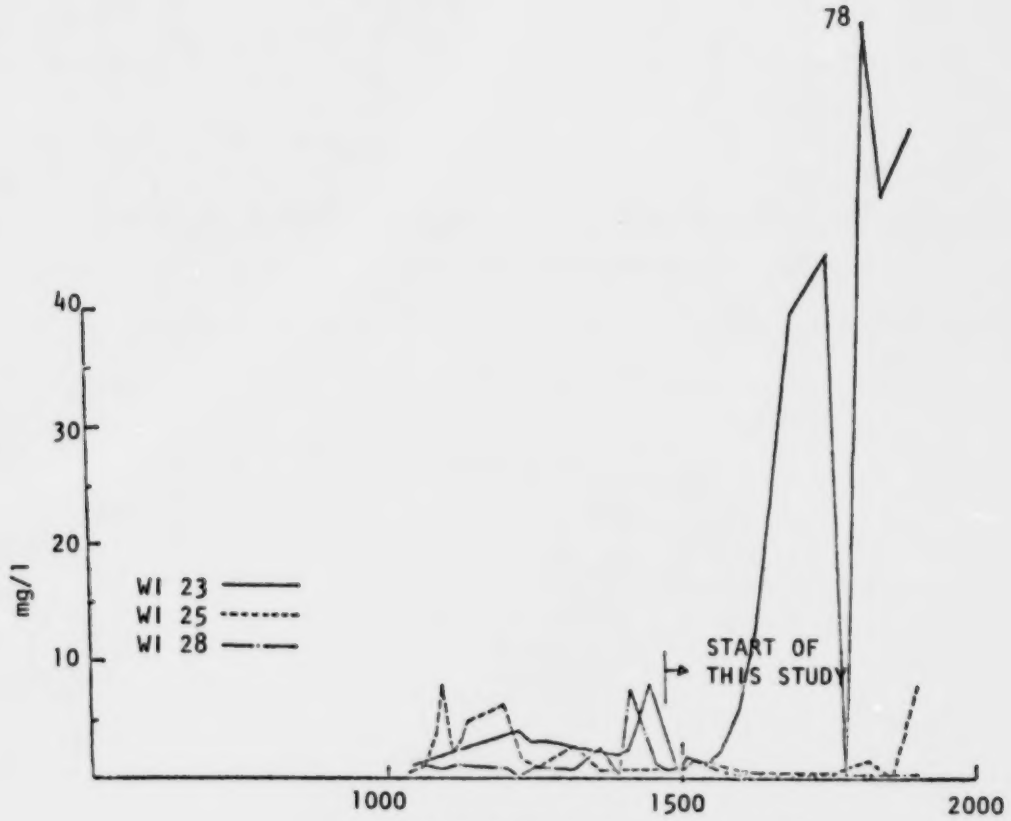


FIGURE 88. FIELD TEST LANDFILL. WI WELL SERIES - IRON CONCENTRATION

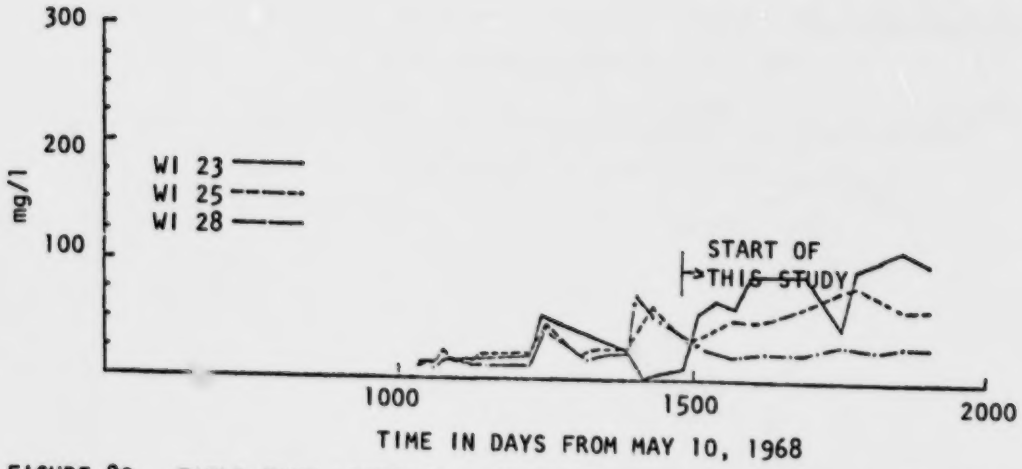


FIGURE 89. FIELD TEST LANDFILL. WI WELL SERIES - CHLORIDE CONCENTRATION

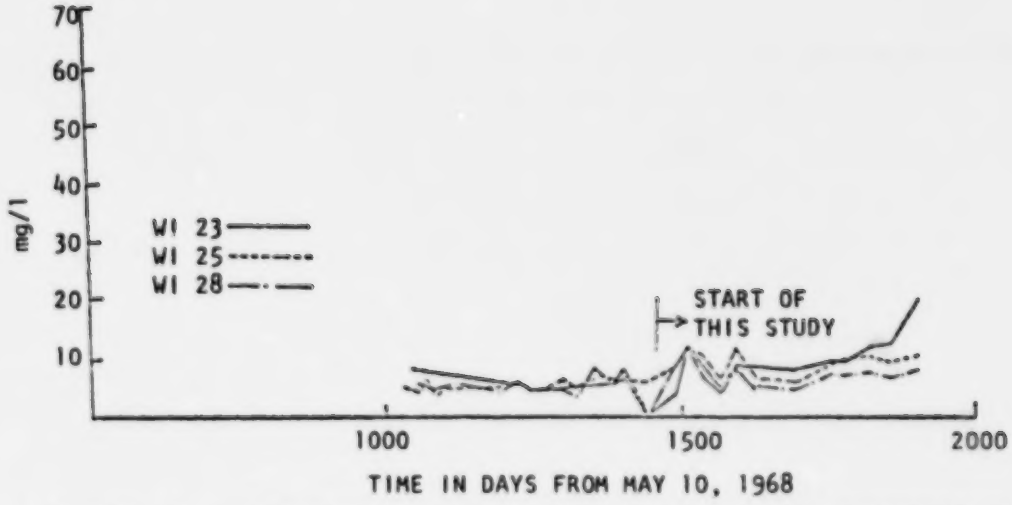


FIGURE 90. FIELD TEST LANDFILL. WI WELL SERIES - Na CONCENTRATION

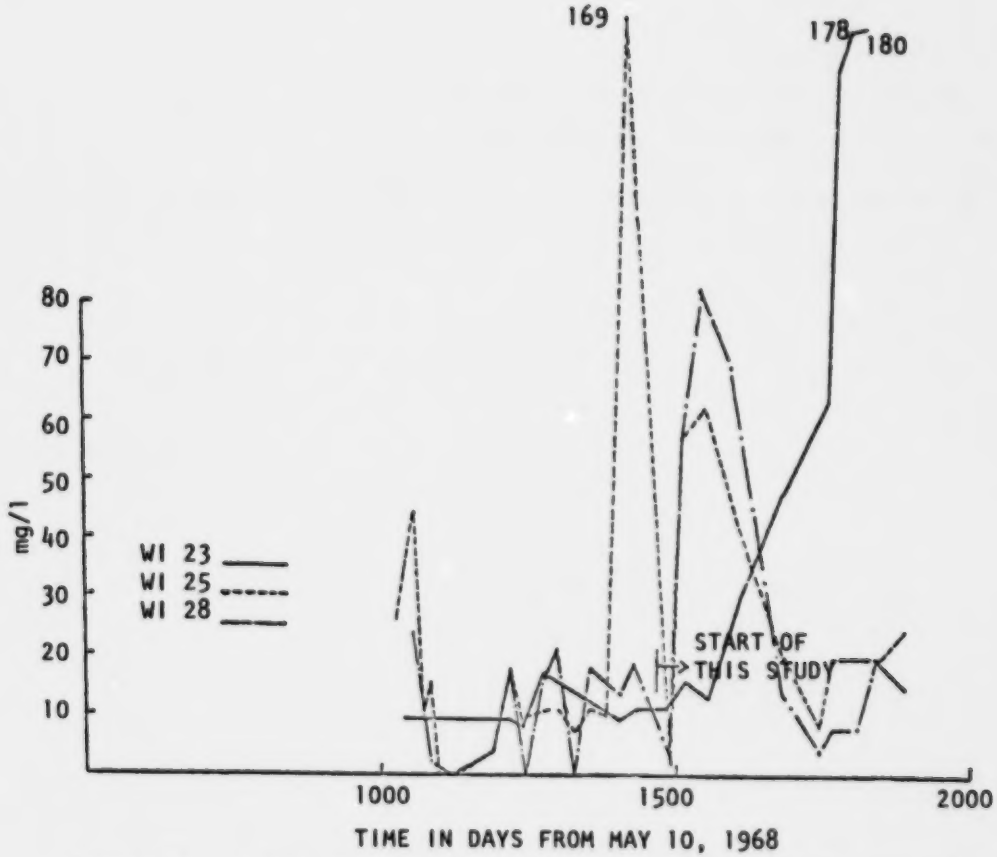


FIGURE 91. FIELD TEST LANDFILL. WI WELL SERIES - COD CONCENTRATION

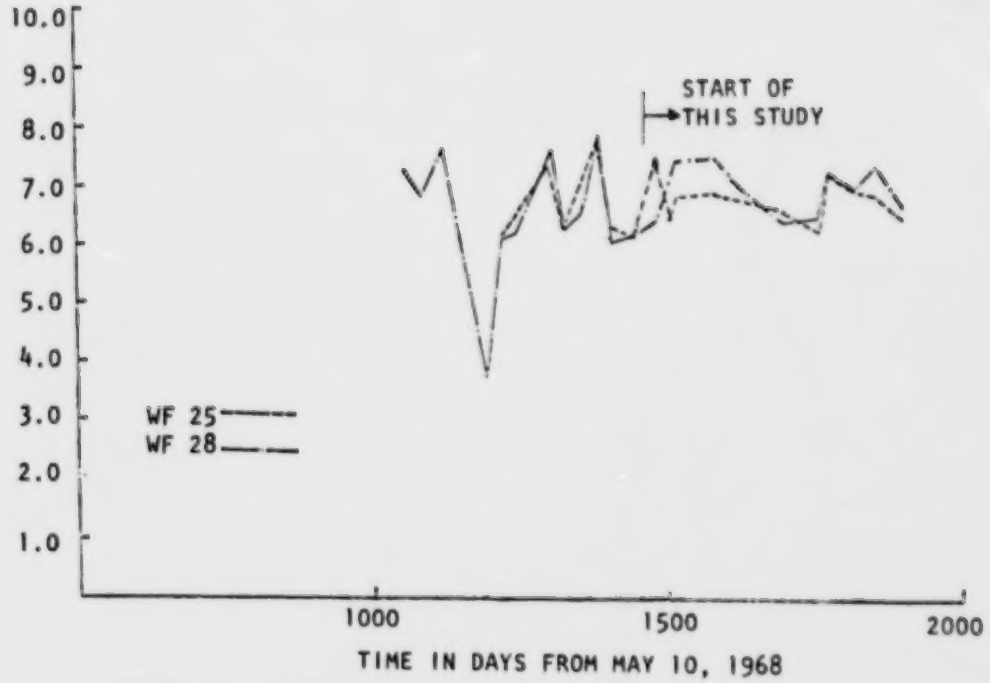


FIGURE 92. FIELD TEST LANDFILL. WF WELL SERIES - pH FACTOR

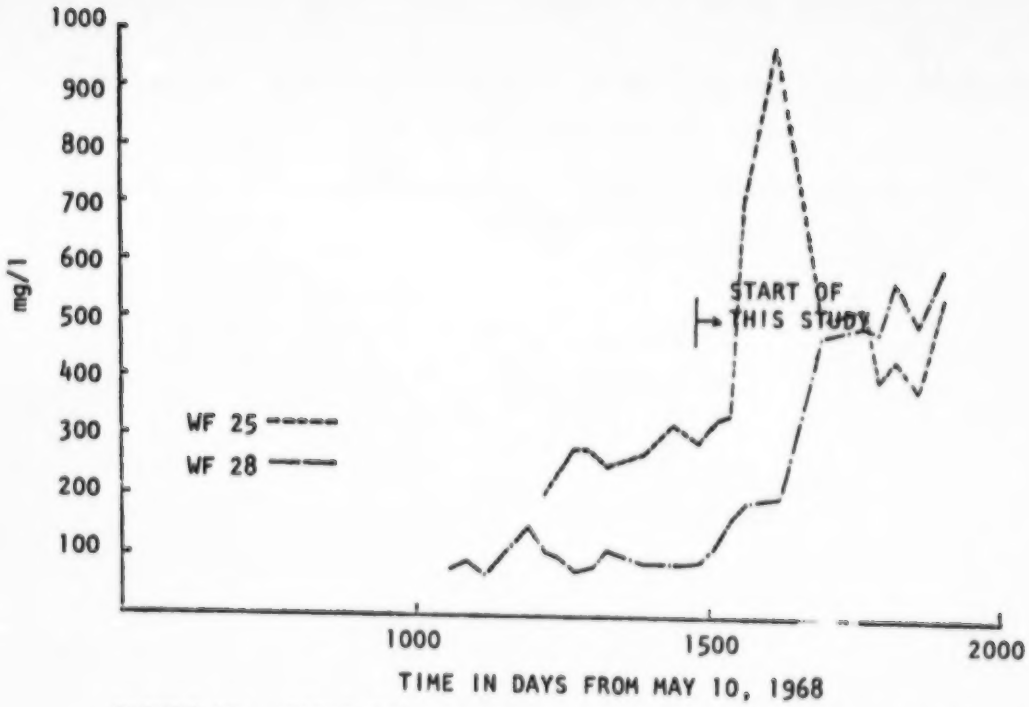


FIGURE 93. FIELD TEST LANDFILL. WF WELL SERIES - TDS CONCENTRATION

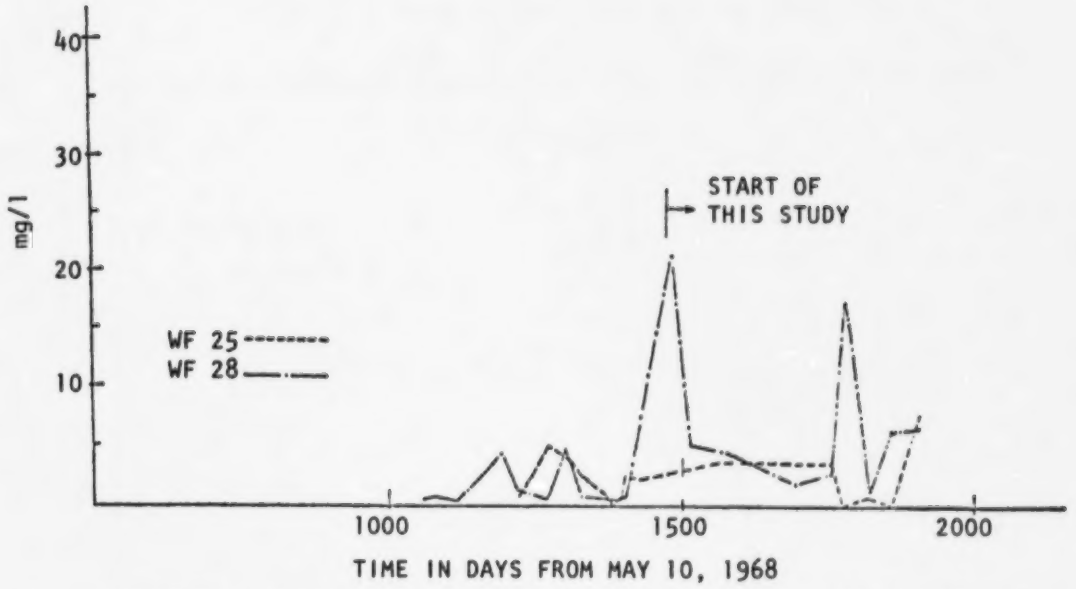


FIGURE 94. FIELD TEST LANDFILL. WF WELL SERIES - IRON CONCENTRATION

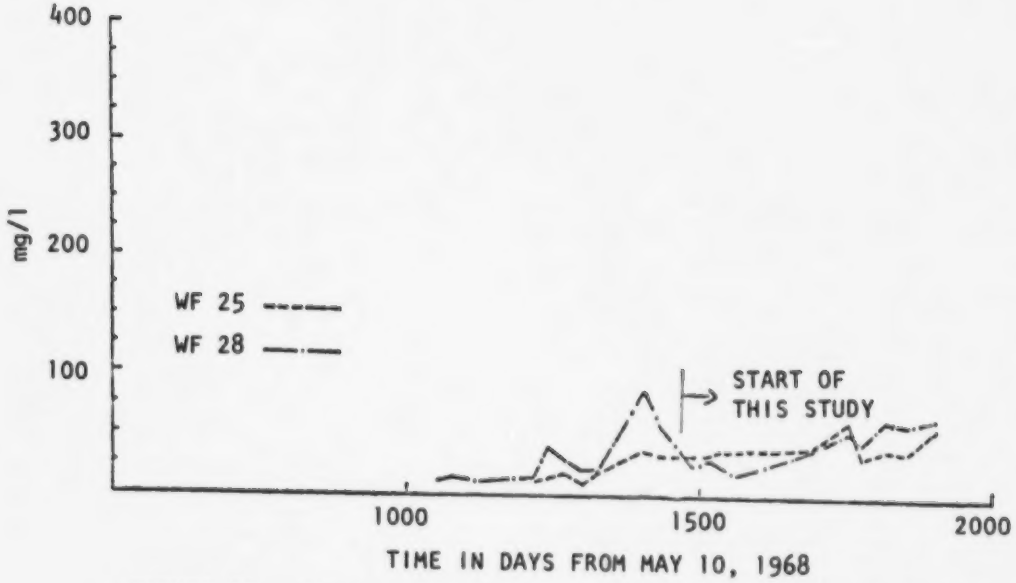


FIGURE 95. FIELD TEST LANDFILL. WF WELL SERIES - CHLORIDE CONCENTRATION

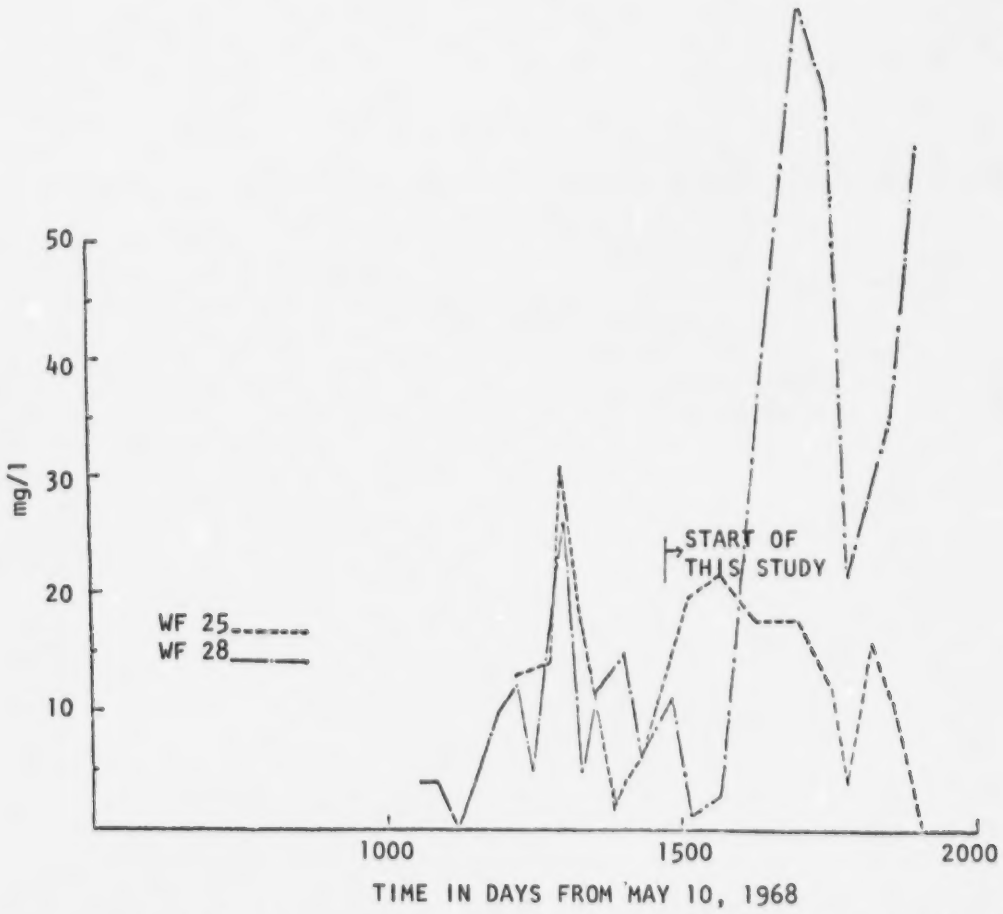


FIGURE 96. FIELD TEST LANDFILL. WF WELL SERIES - COD CONCENTRATION

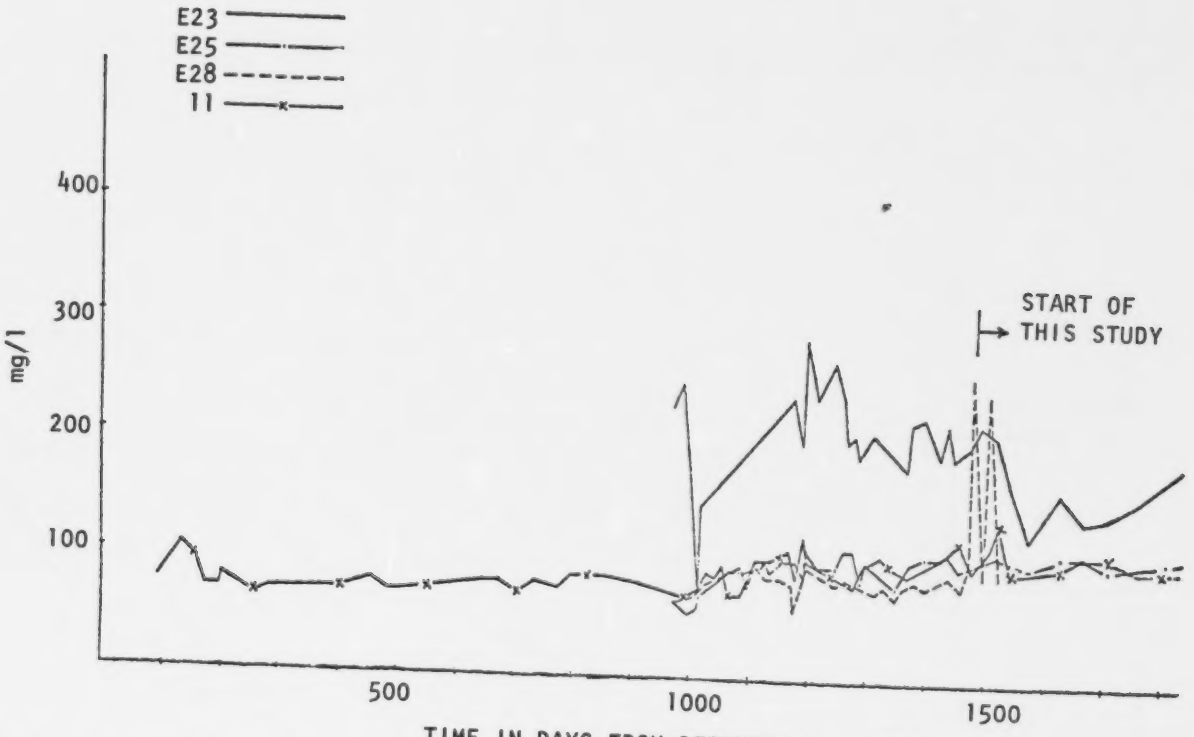


FIGURE 97. TOTAL DISSOLVED SOLIDS - GROUNDWATER

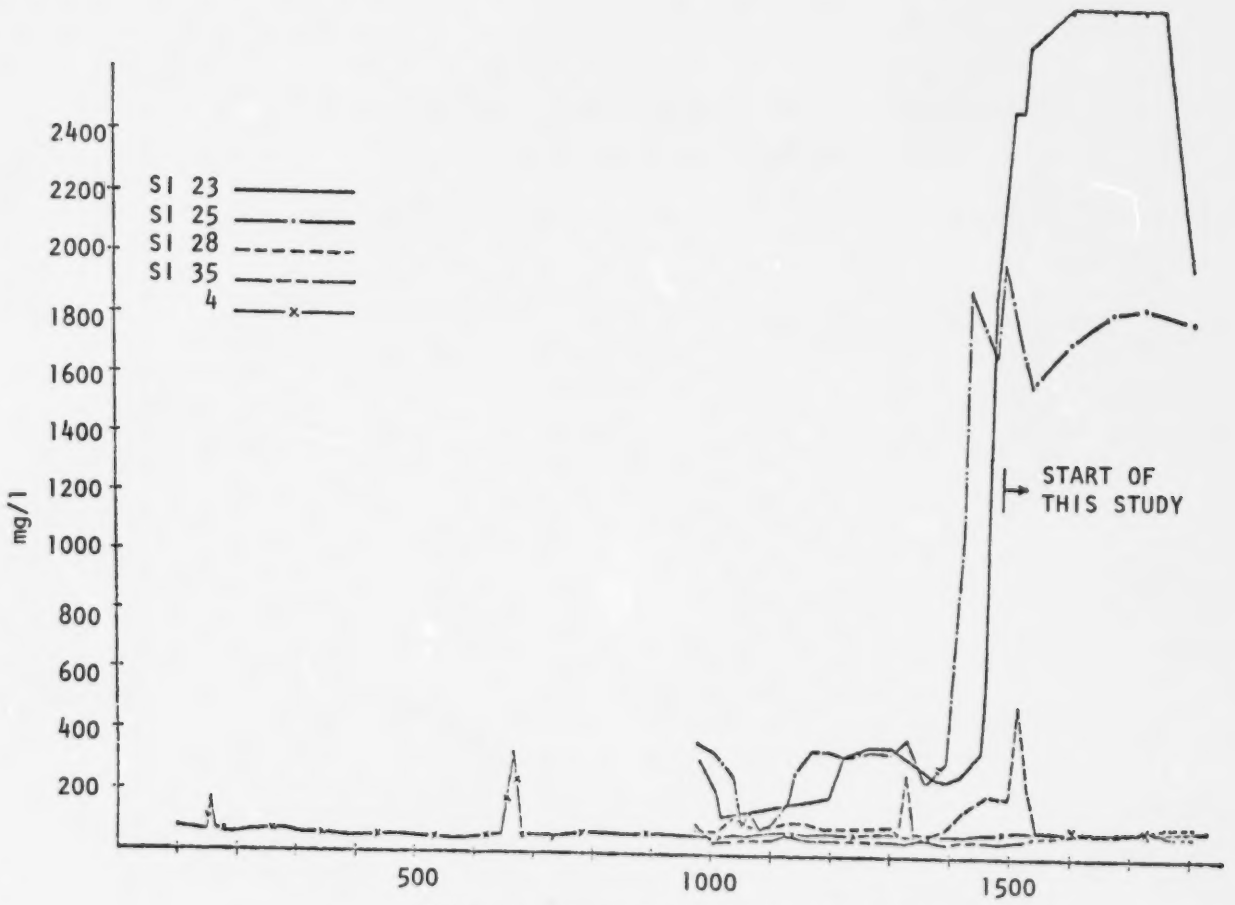


FIGURE 98. TOTAL DISSOLVED SOLIDS - GROUNDWATER

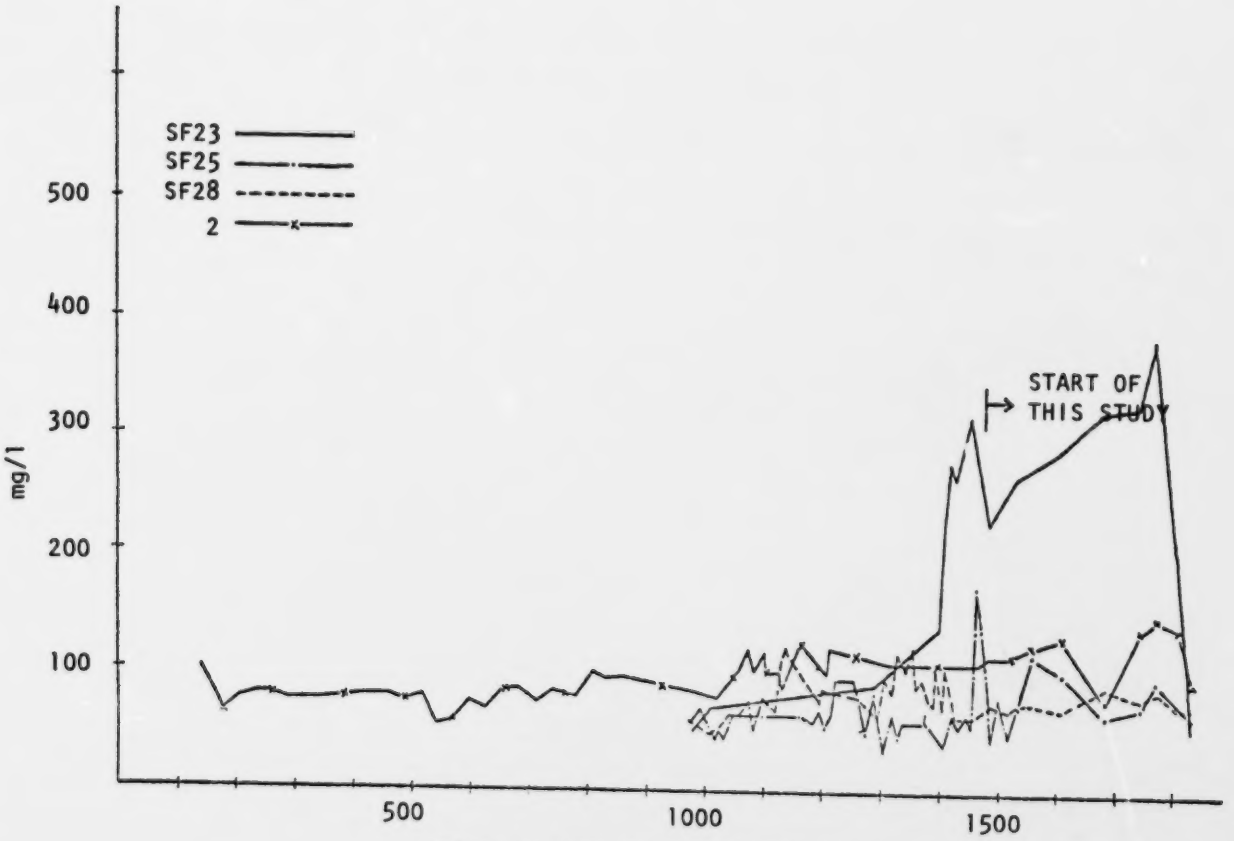


FIGURE 99. TOTAL DISSOLVED SOLIDS - GROUNDWATER

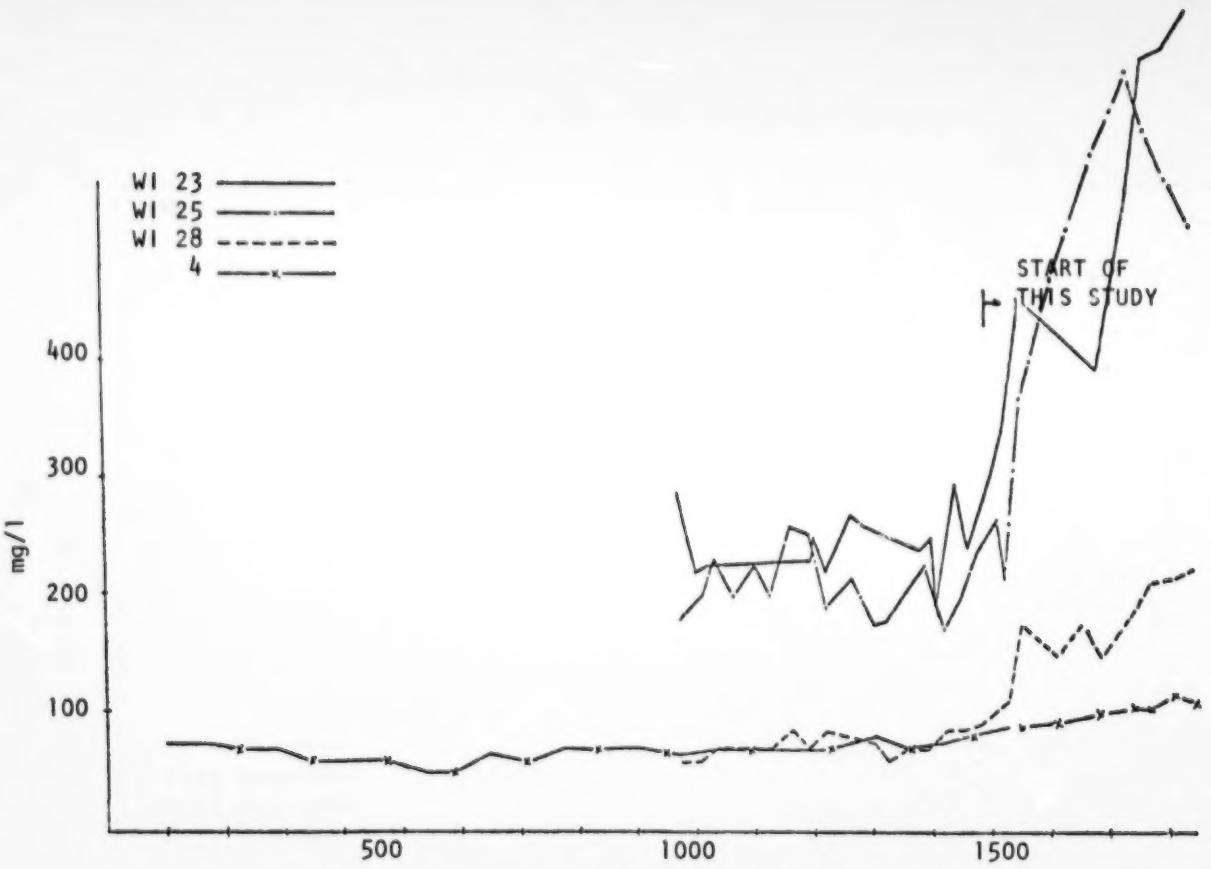


FIGURE 100. TOTAL DISSOLVED SOLIDS - GROUNDWATER

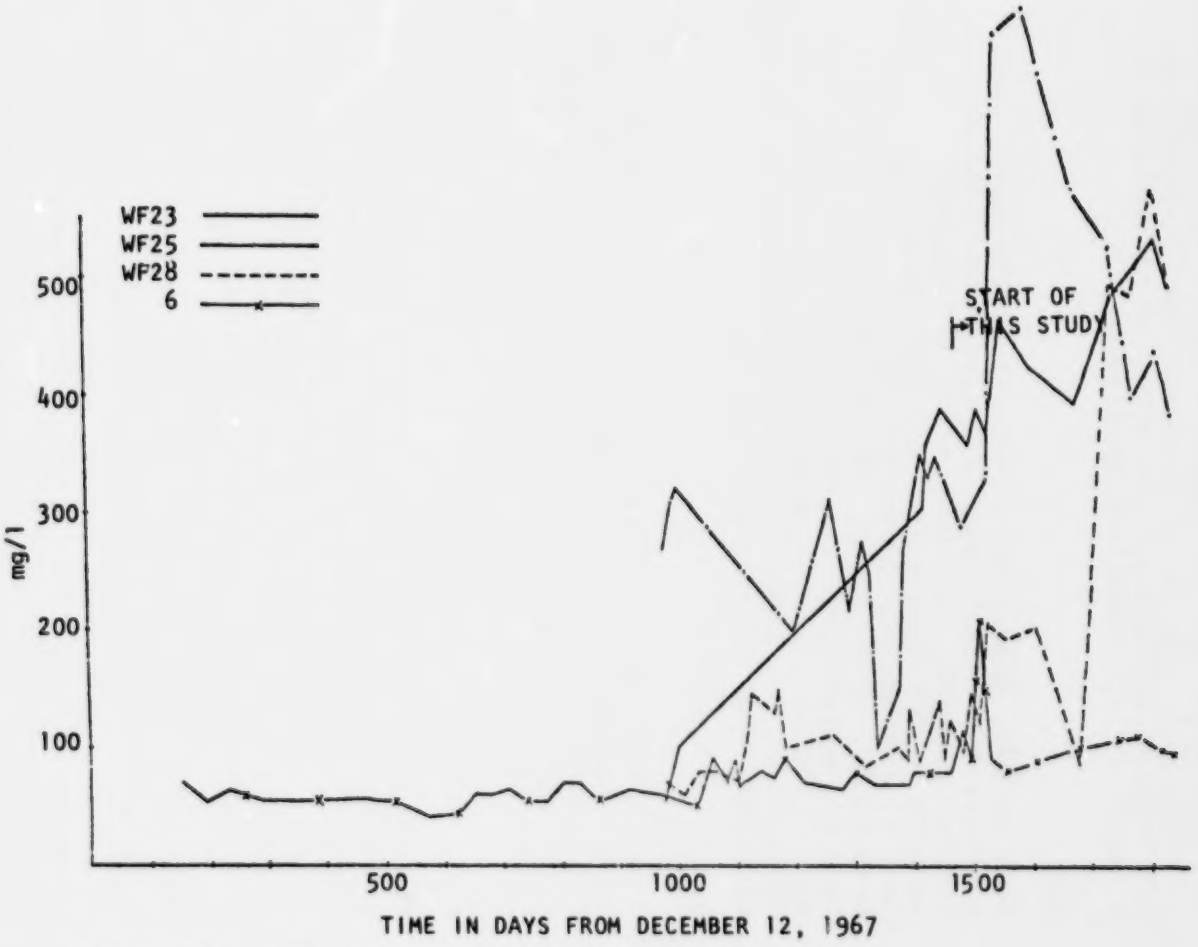


FIGURE 101. TOTAL DISSOLVED SOLIDS - GROUNDWATER

Wells 12 and 13

pH

pH, Figures 50 and 56, tends to remain slightly acidic at about 6.0. The curve continuation is similar to the earlier pattern and there are no indications of a basic (pH >7) condition developing.

COD

Well 12 COD, Figure 51, indicates a continuing low concentration level, generally less than 1800 mg. However, in well 13, COD, Figure 57, increased to between 12,000 mg/l and 13,000 mg/l toward the latter part of the earlier study and the first period of this study. Thereafter, COD values, while higher than those monitored in well 12, were less than 2700 mg/l. The well 13 COD values, while not as high as obtained in the laboratory lysimeter leachate, reached extremely high concentration values.

Iron

Iron in both wells, 12 and 13, Figures 52 and 58, showed maximum concentrations during this study period greatly in excess of those previously reported. Peaks in well 12 reached 463 mg/l and in well 13 almost 900 mg/l.

TDS

Figures 53 and 59 show TDS curves for wells 12 and 13 respectively. Figure 62 is a detailed composite of TDS data for both wells. Generally the TDS concentrations in the wells reached levels greatly in excess of the values previously reported. Well 13 generally had higher TDS concentrations than well 12 and reached levels between 5,000 and 6,000 mg/l.

Chloride

Chloride results are presented in Figure 54 for well 12 and Figure 60 for well 13. Again chloride concentrations reached levels significantly higher than those recorded during the earlier study. This is particularly true in well 13 where levels approached 800 mg/l.

Sodium

Sodium concentration data is presented in Figure 55 for well 12 and Figure 61 for well 13. Concentration patterns differ from those previously reported for chloride. Sodium peaks occurred during the earlier reported study period. However, the sodium concentration patterns are very similar to those for chloride with peaks and valleys occurring at the same time.

Well 3

Well 3 is located down ground water gradient from the refuse area and outside of it.

pH

Generally the pH range, Figure 63, is similar to that obtained for this well during the earlier study. Water quality does not appear to have been affected by the refuse deposit leachate.

COD

Figure 64 presents the COD concentration data. The COD values for the entire period fall within the range of background water quality and does not show any significant influence due to refuse leachate.

Iron

Iron concentrations, Figure 65, were within background levels until approximately 800 days into the test. Thereafter, values increased to approximately 4 mg/l and were time dependent. During the study period covered by this report, concentration levels were significantly less than earlier peak values. While iron concentrations exceeded background levels, the increases were much less than pure leachate concentrations.

TDS

Total Dissolved Solids concentrations are presented in Figure 66. During the period of the study reported herein, concentrations were low, although a slight positive trend can be observed in the figure. While generally TDS values are higher than reported background values, their overall limited variations suggest more background values than leachate influence.

Chloride

The chloride pattern, Figure 67, for the entire study period including that covered by this report generally falls within background values.

Sodium

During the period covered by this report, sodium concentrations, Figure 68, were negligible and well within background levels.

Shallow Well Study

Concentration curves are presented for the E, SI, SF, WI and WF shallow well series in Figures 69 through 96. The curves are for pH, TDS, iron, chloride, sodium, and COD with a few exceptions.

The SI series, which is down ground water gradient from the refuse cell clearly shows the layer influence with depth. Concentrations of each contaminant decrease with increasing depth to approximately background concentration levels.

The SF series further down ground water gradient than the SI series shows little, if any, change from background concentration levels.

The E series is adjacent to the test cell, but somewhat down gradient. This series shows the effect of lateral as well as vertical dispersion. Concentrations of the various contaminants are higher than background, but generally less than found in the SI series at the same depth.

The WI and WF series patterns are similar to those for the SI and SF series and also reflect lateral as well as vertical dispersion effects.

Overall the shallow well behavior patterns developed during this study period are continuations of the earlier patterns with some large increases recorded only in those wells most affected by leachate migration (SI series).

Ground Water Total Dissolved Solids Study

Figures 97 through 101 show comparisons of TDS concentrations for selected deep and shallow well series. The purpose of the comparisons was to establish layer effects within the ground water system.

The results of these comparisons clearly indicate that contaminant layering exists within the ground water system and could be defined with relative ease. To a great extent this delineation of the contaminant layer became easier because of the data gathered during this study period because the degree of shallow well contaminant concentrations are most obvious in the SI series, Figure 98, and the WI series, Figure 100.